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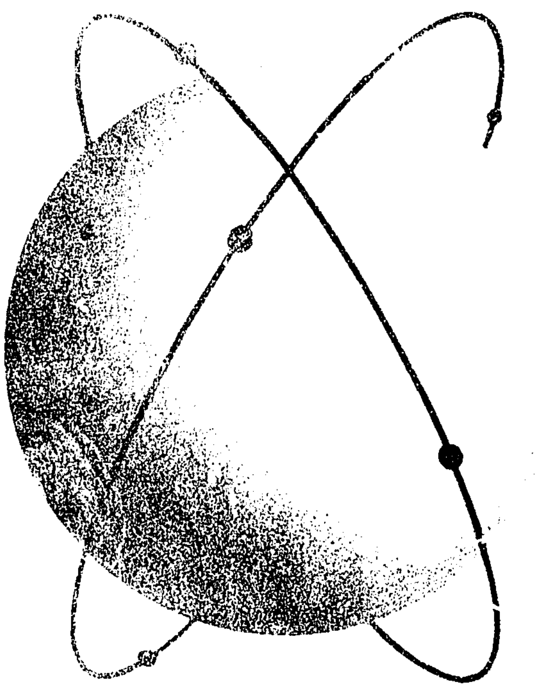
ABSTRACT

As the eleventh lesson of the Articulated Multimedia Physics Course, instructional materials are presented in this study guide with relation to impulse and momentum. The topics are concerned with "quantity of motion," unit conversion, and related conservation laws. The content is arranged in scrambled form, and the use of matrix transparencies is required for students to control their learning activities. Students are asked to use magnetic tape playback, instructional tapes, and single concept films at the appropriate place in conjunction with the worksheet. Included are a homework problem set and illustrations for explanation purposes. Related documents are SE 015 963 through SE 015 977. (CC)

ARTICULATED MULTIMEDIA PHYSICS



LESSON

11

NEW YORK INSTITUTE OF TECHNOLOGY
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ARTICULATED MULTIMEDIA PHYSICS

Lesson Number 11

IMPULSE AND MOMENTUM

IMPORTANT: Your attention is again called to the fact that this is not an ordinary book. It's pages are scrambled in such a way that it cannot be read or studied by turning the pages in the ordinary sequence. To serve properly as the guiding element in the Articulated Multimedia Physics Course, this Study Guide must be used in conjunction with a Program Control equipped with the appropriate matrix transparency for this Lesson. In addition, every Lesson requires the availability of a magnetic tape playback and the appropriate cartridge of instructional tape to be used, as signaled by the Study Guide, in conjunction with the Worksheets that appear in the blue appendix section at the end of the book. Many of the lesson Study Guides also call for viewing a single concept film at an indicated place in the work. These films are individually viewed by the student using a special projector and screen; arrangements are made and instructions are given for synchronizing the tape playback and the film in each case.

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If you live in the country, you may have used a .22 caliber rifle for target practice or for shooting small game; if you're city bred, you have probably tried your marksmanship in a shooting gallery at an amusement park. Do you know that the same cartridge used in a .22 caliber rifle may also be used in a short-barreled pistol having a chamber designed for it? But a hunter never uses a pistol even though it is easier to carry and certainly more convenient in other ways. Why?

The first thing you'll say is that the rifle is more accurate. This is quite true, of course. But excellent accuracy with a pistol can be developed too. Is there another answer?

Sure, there is; you probably would answer at once that <u>the rifle has a greater range</u>. Again, you would be quite right. In this case, however, we wonder if you have ever given any thought to the reasons underlying the longer carrying-distance of a bullet fired from a rifle as compared with the same bullet impelled by the same powder charge when fired from a pistol.

Think this out along with us. The acceleration of the bullet or "slug" is determined by the force applied to it and the mass of the bullet according to Newton's Second Law of Motion:

$$a = \frac{F}{m}$$

Please go on to page 2.

The magnitude of the force applied to the bullet is governed by the kind and quantity of the explosive propellant used. If the same cartridge is used in rifle and pistol, then the same force is applied to the slug in each case. By the same reasoning, the mass of the slug is also a constant factor. So, if both F and m are identical, the acceleration imparted to the bullet by the pistol must be identical to the acceleration imparted to it by the rifle. Why, then, does the rifle have a much greater firing range?

As you think a while, you will probably conclude that it is not the acceleration of the bullet which determines the range but rather its speed as it leaves the gun. This is a valid conclusion; a slug with a high muzzle velocity will go farther than one with a low muzzle velocity, all other factors being equal. Returning to the rifle and pistol contrast, you must then be prepared to answer this question: If the force, mass, and acceleration of the slug are the same for both weapons, why does the rifle bullet have a greater muzzle velocity than the pistol bullet?

The answer is almost self-evident at this point. The longer barrel of the rifle allows the force of the exploding charge to act upon the bullet for a longer period of time. So an apparently new consideration enters here: The speed of an object being accelerated by a force is dependent upon both the magnitude of the force and time during which the force acts. As you will see shortly, we can combine force and time to form an important quantity called impulse.

Please go on to page 3.

Let us look at another aspect of a similar situation. When you catch a thrown ball, you cause a very sudden decrease in its speed. An outfielder in a baseball game wears a fielder's mitt to avoid hurting his hands as he suddenly brings the ball to rest. But if a tennis ball had come the same distance at the same speed, the mitt would not be necessary. The tennis ball, of course, has a smaller "quantity of motion" than a baseball because it has a smaller mass. On the other hand, you wouldn't want to catch a tennis ball with your bare hands if it were delivered to you by a big league pitcher from the pitcher's box to catcher's position in the form of a real fast ball. It's the same tennis ball, so its mass is not different; but it does have a much greater "quantity of motion" than before because it is traveling at a vastly greater velocity.

The quantity of motion possessed by a moving object, then, depends upon two factors: the mass of the body and the velocity with which it moves. Just as we are able to combine force and time to form a single quantity called impulse, we can combine mass and velocity to form another important quantity called momentum.

These quantities--their definitions and interrelationships--form the core of this lesson. As these basic understandings gradually take shape in your mind, your appreciation and comprehension of motion will be greatly enhanced. Impulse and momentum considerations have extremely important roles in all phases of physics from the macrouniverse of galaxies, stars, and planets right down to the microuniverse of electrons, protons, and neutrons.

Before continuing, please turn to page 156 in the blue appendix.

Walk over to the door of the room in which you are now working, open it half way, and exerting a small force on the edge of the door in the right direction, push the door gently with the tip of your forefinger until it swings with sufficient velocity to just barely latch closed without slamming.

Open the door again to its former position. This time, ball your fist and punch the door at the same spot as before (not too hard, now!) so that it again latches closed without slamming.

Here are two different approaches to the same problem, the results being identical in each case. You want to close the door without slamming it; you may do it with a long, gentle push using the tip of a finger, or you may do it by means of a sharp punch at the same point. (The latter may take some practice, but it can be done.)

How do these approaches differ? Comparing the "punch" action to the gentle pushing action, you might say that the punching action involves which of the following?

(1)

A A smaller force for a longer time.

B A larger force for a shorter time.

C A larger force for a longer time.

YOUR ANSWER --- B

You are correct. Momentum = $\vec{p} = m\vec{v} = kg \times \frac{m}{sec} = \frac{kg\text{-}m}{sec}$.

NOTEBOOK ENTRY
Lesson 11

(Item 1)

(c) The unit for impulse in the MKS system is the nt-sec.

2. Momentum

(a) Momentum is defined as the product of the mass of a body in motion and the velocity of the body. If the body moves with uniform velocity, then its momentum is constant; if the velocity changes, then its momentum changes.

(b) Momentum is a vector quantity since it is the product of a vector (velocity) and a scalar (mass). The defining equation is:

$$\vec{p} = m\vec{v}$$

where $\vec{p}$ = momentum.

(c) The unit for momentum in the MKS system is the $\frac{kg\text{-}m}{sec}$.

Our principal concern in this lesson thus far has been the definition of our terms and the physical nature of the quantities we call impulse and momentum. We have seen that the impulse of a force depends not only on the magnitude of the force but also upon the time in which it acts; we have also seen that the momentum imparted to a body is measured not only by the velocity the body acquires but also by the mass of the body. We now propose to show the connection between impulse and momentum. Their association is a close one indeed.

This association is easily shown by referring to our statement of Newton's Second Law. Write the equation for the Second Law on a fresh piece of scrap paper and then turn to page 6.

CORRECT ANSWER: You may have written either $\vec{F} = m\vec{a}$ at this time, or $\vec{a} = \frac{\vec{F}}{m}$.

As you look at the relation:

$$\vec{F} = m\vec{a}$$

you will observe it has something in common with both impulse and momentum. Force $\vec{F}$ is an important part of impulse ($\vec{F}\Delta t$), while mass m has much to do with the momentum ($m\vec{v}$) of a moving body.

In order to proceed further, we will want to express acceleration in terms of velocity and time.

Which of the statements below is the general definition of acceleration in terms of velocity and time?

(11)

A $a = \frac{\Delta v}{\Delta t}$

B $\vec{a} = \frac{\vec{v}}{t}$

C $a = \frac{\Delta d}{\Delta t}$

D $a = \frac{\text{change of speed}}{\text{time required}}$

YOUR ANSWER --- C

You are correct. If doubling either m or v causes the quantity of motion to double, then quantity of motion must be proportional to both these quantities.

To help you develop your understanding and to crystallize your concept of quantity of motion, let us consider an example. A heavy-duty locomotive having a very large mass is allowed to roll very slowly down a gentle incline.

As shown in Figure 1, the locomotive carries a pointed steel probe at the front. After rolling a few feet, the probe meets a large wood stop. Naturally, the probe will penetrate the wood stop to a definite depth before the retarding action can bring the locomotive to a halt.

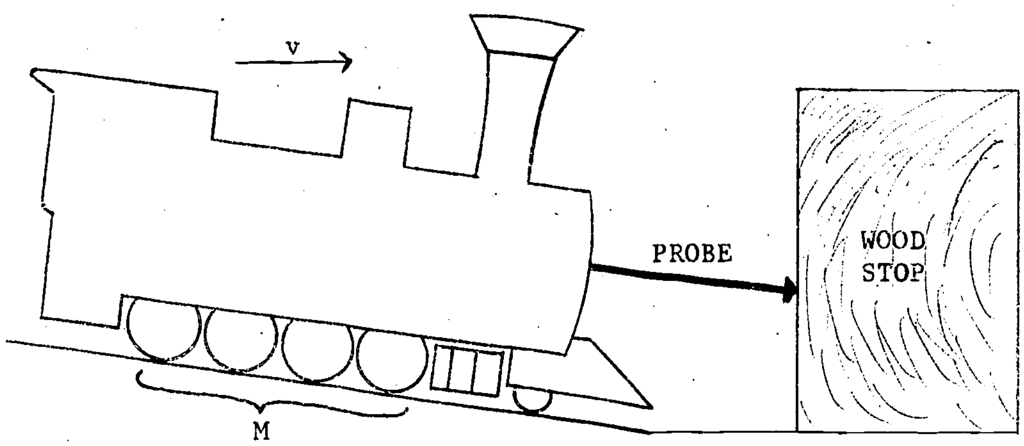

Figure 1

Let us call quantity of motion by its accepted name: momentum. Let us also agree that the depth to which this particular probe penetrates this particular wood stop can serve as a measure of the momentum of the locomotive. Obviously, if the momentum of the locomotive is increased somehow, the depth of penetration will be which of the following?

(7)

A Increased.

B Decreased.

C Remain the same.

YOUR ANSWER --- A

We've asked you to adhere to our convention relating to the sign of velocity. If the velocity is to the right, it is (+). What is the direction of v_1--to the right or the left?

Please return to page 56. Select the right answer.

YOUR ANSWER --- A

Check back on your notes. The symbolic definition of momentum involves mass and velocity, not force and time.

Please return to page 122; then choose the answer that fits our definitions.

YOUR ANSWER --- A

You will have to be careful with units of time. Very frequently the time is given in minutes or fractions of minutes. Ordinarily, you have a choice of two courses: (1) If you multiply newtons by minutes, the final unit of impulse will then be nt-min which is perfectly good in itself; (2) You may want to change the minutes to seconds and thereby obtain the impulse in newton-seconds.

In this case, following the first alternative:

$$\begin{aligned} \text{impulse} &= \vec{F}\Delta t = 80 \text{ nt} \times 0.005 \text{ min} \\ &= 0.40 \text{ nt-min} \end{aligned}$$

However, this answer does not appear in the list given.

Please change the minutes to seconds, work out the impulse in newton-seconds, and then return to page 116 so that you may choose the right answer.

YOUR ANSWER --- C

Very possibly it does. However, the type of firing mechanism--whether the rifle is bolt-action, pump-action, or lever-action--has nothing whatever to do with the relationship of momenta.

Regardless of the mechanism, no force is released until the firing pin hits the cartridge, and then the same amount of force is released no matter what mechanism is used to fire the bullet.

Please return to page 100 and choose a better answer.

YOUR ANSWER --- C

No.

You didn't watch your decimal point. You do have the right units for momentum, however.

Please return to page 147 and choose the right answer.

YOUR ANSWER --- C

Correct. The velocity of m_2 is v_2 which is given as zero just before impact in Figure 5 on page 50. Hence, m_2 is at rest with respect to the table on which it rests.

As you watch the collision take place, you see that m_1 is suddenly brought to rest, while m_2 takes off in the same direction as the initial motion of m_1. We indicate this by labeling m_1 in the right diagram (After Impact) with the symbol $v_3 = 0$ to show what has happened. In addition, m_2 is now rolling to the right with a velocity of v_4.

Now refer to notebook entry 4(b). In this statement of the <u>conservation principle</u>, we say that in an isolated system of interacting masses, the total momentum remains unchanged, i.e., the momentum is conserved. Before impact, the momentum of the system is derived entirely from m_1, having the magnitude m_1v_1. The momentum of m_2 before impact was zero since it was at rest; hence $m_2v_2 = 0$. After impact, the momentum of m_1 is $m_1v_3 = 0$ since this ball has come to rest, while the momentum of the system now is derived wholly from m_2, its value being m_2v_4. Which of the following would you select as the best statement of notebook entry 4(b) as applied to this situation?

(31)

A $m_1v_1 + m_2v_2 = m_1v_3 + m_2v_4$

B $m_1v_1 + m_2v_2 = m_2v_3 + m_1v_4$

C $m_1v_1 = m_1v_4$

D $m_1v_1 = m_2v_4$

YOUR ANSWER --- C

Well, we can try this and see:

F		Δt	Result
6	÷	0.1	60
3	÷	0.2	15.5
1	÷	0.6	1.66
0.5	÷	1.2	0.41

Not so good. The results are all different. Yet each force acting for the time shown in the same row produced exactly the same effect as the other pairs of force and time. That is, the impulse of each force was the same. It seems evident, then, that we cannot find the impulse of a force by dividing the force by the time. If we try this operation in reverse, that is time interval divided by force, we will find that this doesn't work any better.

Please return to page 33. You can find the right answer.

YOUR ANSWER --- C

It is quite possible that you did not notice the constancy of momentum in the last example involving the carts. The carts had different masses and, when they interacted as the spring expanded, they separated at different velocities. Yet the change of momentum of cart m_1 (Δp = 0.2 kg-m/sec) was numerically the same as the change of momentum of m_2 in the opposite direction. This suggests that when bodies interact in this manner, they will always separate with equal changes of momentum in opposite directions. But a single experiment never <u>proves</u> anything; and to establish a physical principle, we must have many, many experimental proofs of its validity.

So, in the boy-pushes-man experiment, you might detect this same constancy of momentum if you compute the Δp for the boy and for the man and then compare them. Suppose you do just that.

Then return to page 151, please. The right answer should now be easy to choose.

YOUR ANSWER --- D

We have repeatedly emphasized the vector nature of acceleration. From your study of Newton's laws and the concepts in circular motion, you are fully aware of the fact that acceleration cannot be described completely unless both magnitude and direction are included in the description.

In defining a vector quantity, the elements which make up the definition must reflect the vector nature of the defined term. You have seen that a vector multiplied or divided by a scalar always yields a vector result. But you have never witnessed a case where a scalar divided by a scalar will yield a vector.

This choice of answer is incorrect because it does just this. Speed is a scalar quantity and so is time. Dividing one by the other cannot possibly give you a vector quantity like acceleration.

Please return to page 6. Choose an answer which truly defines acceleration in the most general way.

YOUR ANSWER --- A

This answer contains two errors in assignment of units. You probably were careless.

Please return to page 31. Be more careful this time.

YOUR ANSWER --- A

You are correct. The momentum can be increased by increasing the mass of the locomotive, its velocity, or both. Any means used to do this will give the engine a greater quantity of motion and hence will increase its ability to drive the probe more deeply into the wood.

Refer to Figure 1 on page 7. Notice how we have indicated the mass and velocity of the locomotive:

M = mass v = velocity

Obviously, the momentum has been derived chiefly from the very large mass rather than from the very small velocity.

Next let's imagine that the probe is removed from the front of the engine and that the probe is fired into the same wood stop by means of a specially designed spring gun. The spring will be compressed just enough to cause the probe to penetrate into the stop <u>to the same depth as it did when mounted on the engine</u>.

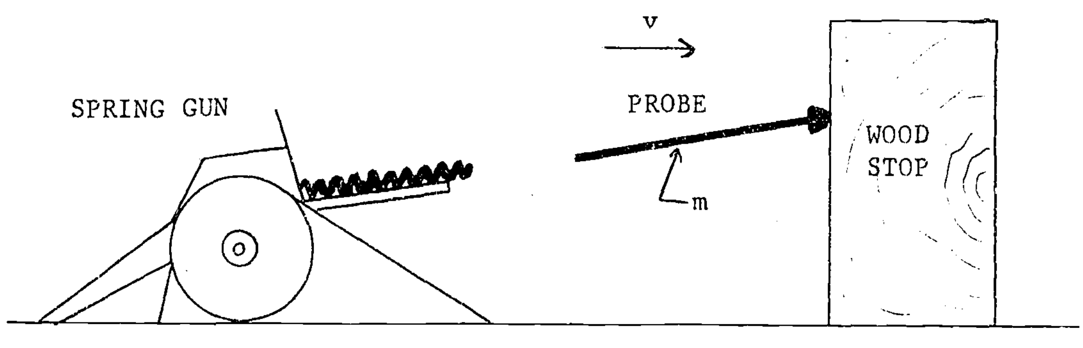

Figure 2

If the depth is the same, then the __________ of the probe in this situation must be exactly the same as it was when it was mounted on the locomotive. What's the missing word?

Write the word; then turn to page 141 to check your answer.

YOUR ANSWER --- D

When the cars couple together, in effect they form a single moving body. For consistency, we have assigned v_3 as the velocity of the empty freight car after impact and v_4 as the velocity of the loaded freight car after impact. But if the two cars form a single body, can v_3 be less than v_4? It did not bounce away from the loaded car.

Please return to page 88 and select the right answer.

YOUR ANSWER --- C

The object was decelerated to rest and then accelerated in the opposite direction. Thus, its change of velocity must be assigned a negative sign This means that its change of momentum was negative as well, since m is a scalar and is always taken as positive.

What does this tell you about the impulse that produced this change of momentum?

Please return to page 39 and select a better answer.

YOUR ANSWER --- D

You appear to be on the right track. Your error lies in having used the wrong unit for mass.

Please return to page 153; then locate your error and correct your choice.

YOUR ANSWER --- A

You can't be sure.

The hole is to the left of the golfer. Suppose he swings at the ball in such a way as to drive it to the right or straight ahead. Would the ball go into the hole then? Of course not.

Please return to page 134. Be careful in your answer choice.

YOUR ANSWER --- A

You are correct. Careful experiments verify this prediction. The two masses retreat from each other at the same speed in opposite directions. (Their velocities are not the same because of this difference in direction, of course.)

Continuing with the experiment in Figure 3 on page 154, we increase mass m_2 to twice its former value, while m_1 is unchanged. So we have a relatively large mass on the right and a smaller one on the left. We compress the spring, then burn the cord, and observe the relative speeds of the two carts as the spring suddenly expands.

Making use of your past learnings in physics, what do you think would be true of the speeds of the two carts now?

(25)

A The speed of m_2 would be greater than that of m_1.

B The speed of m_1 would be greater than that of m_2.

C The speeds of m_1 and m_2 would be the same.

YOUR ANSWER --- C

This answer is not right.

It is probable that you went astray in adding $m_1 + m_2$ in the denominator of the right side of the equation. You may have forgotten that when you add two numbers having different powers-of-ten, you must change one or the other of the numbers so that the exponents of 10 are the same.

In our case, you are trying to add:

$$6.0 \times 10^4 + 1.2 \times 10^5$$

If you wish, you can change the first term to 0.60×10^5 and then add:

$$0.60 \times 10^5 + 1.2 \times 10^5$$

which is perfectly all right because both powers-of-ten have the same exponent. Or, it is just as correct to change the second term to 12×10^4 and then add:

$$6.0 \times 10^4 + 12 \times 10^4$$

Once you get this sum right, the rest of the problem should be easy for you.

Please return to page 51. Work the problem through again and then choose the correct answer.

YOUR ANSWER --- A

This answer is incorrect.

You should by now begin to realize the difference between the natures of impulse and momentum. Remember that momentum is a property of the moving body and has units which refer to the mass and velocity of the body. But impulse, which is what we are asking for here, is a property of the force which induces motion and has units of force and the time duration of the force.

Please return to page 130. You should be able to work this out now.

YOUR ANSWER --- C

You are correct. The (-) sign shows that there is a retarding force of 30 nt acting on the moving body. Retardation can occur only if the direction of the force is opposite that of the motion.

Here is your last question. What is the momentum of the object before and after the force acts?

Momentum is given by p = mv. Before the force acts, the momentum of the object is:

$$p = 10 \text{ kg} \times 10 \text{ m/sec} = 100 \text{ kg-m/sec}$$

The momentum after the force acts is given by the same relation, but the new velocity must be used for v. Remembering that momentum is a vector quantity and that the new velocity is opposite in direction compared to the initial velocity, what would you say the momentum is after the force acts?

(23)

A -120 kg-m/sec

B -20 kg-m/sec

C 20 kg-m/sec

YOUR ANSWER --- A

Something went wrong here!

If the mass of the ball is 0.50 kg, then the weight can't be 0.50 nt, also.

On the Earth if the mass m of an object is known, then its weight is given by Newton's Second Law as:

$$w = mg$$

Go back to the original question by turning to page 67, please. The answer should now be evident.

YOUR ANSWER --- B

Not true.

There are two terms that drop out, not just one.

Please return to page 54. Read the question carefully. Don't be impulsive. You can easily choose the right answer.

YOUR ANSWER --- A

This answer indicates that you should review your notes on vectors and scalars in general.

One or both of the quantities in your answer choice are mislabeled as vectors or scalars.

Think about this again or look up the definitions of scalars and vectors.

Please return to page 84. Don't guess. Be sure you know which quantity is vector or scalar before making your next choice.

YOUR ANSWER --- A

You are correct. Before impact, the total momentum of the system was $m_1v_1 + m_2v_2$. After impact, the total momentum of the system was $m_1v_3 + m_2v_4$. By setting these sums equal to each other, we explicitly say that the momentum was conserved in the interaction between the balls. That is, the momentum before impact was equal to the momentum after impact, considering the isolated system as a whole.

We can go further with this particular example. Refer to Figure 5 on page 50. Two of the four velocities with which we are dealing are zero. That is, $v_2 = 0$ and $v_3 = 0$ because initially m_2 is at rest, and after impact, m_1 comes to rest.

With this in mind, we can simplify the equation in the above answer by dropping two of the terms. When you do this, what is the result? Write the resulting equation <u>before</u> you turn to page 93 to check your work.

CORRECT ANSWER: The impulse that gives an 8.00 kg mass a change of velocity of 4.00 m/sec is 32.0 nt-sec.

The solution:

(1) We start with: $F\Delta t = m\Delta v$
(2) Substituting: $F\Delta t = 8.00 \text{ kg} \times 4.00 \text{ m/sec}$
(3) Solving: $F\Delta t = 32.0 \text{ kg-m/sec}$
(4) We want to express impulse in nt-sec, however. Since a newton is a kg-m/sec^2, we see that if we multiply newtons by seconds, we come out with:

$$\frac{\text{kg-m}}{\text{sec}^{\cancel{2}}} \times \cancel{\text{sec}} = \frac{\text{kg-m}}{\text{sec}}$$

Thus, the 32.0 kg-m/sec is the same thing as 32.0 nt-sec.

From this point on, we need not worry about units just as long as we remain consistently in the MKS system. That is,

Impulse is measured in newton-seconds.
Momentum is measured in kilogram-meters per second.
Since impulse = the change in momentum, then the newton-second is always the equivalent of the kilogram-meter per second.
Finally, to remain consistent, we must measure force in __(w)__, time in __(x)__, mass in __(y)__, and velocity in __(z)__.

To complete the sentence above, select the correct group of units from those below.

(14)

A (w) kilograms, (x) seconds, (y) newtons, (z) meters/sec.

B (w) newtons, (x) seconds, (y) kilometers, (z) meters/sec.

C (w) newtons, (x) seconds, (y) kilograms, (z) meters/sec.

YOUR ANSWER --- D

Have you forgotten what you started out to find? The listing of data that we asked you to copy should tell you what you are required to determine. We must conclude that you didn't follow instructions.

Please return to page 88 to review and copy the listing.

YOUR ANSWER --- B

You are correct. A punch is a sharp, quick blow. It is the source of a large force acting for a relatively short time.

Continuing with the analysis, we see that a large force acting for a short time can produce the same effect as a small force acting for a long time. There is a certain equivalence in the two sets of circumstances. When force and time are both involved in a certain action, we shall speak of the impulse of the force; we shall say that one force impulse is equal to another if both cause the same effect on a mass insofar as its final velocity is concerned. In our example, the same mass (the door) was acted upon in the two situations, and in each one the door achieved the same final velocity (just latching closed). We say that the impulse was the same in both cases.

Taking some figures from a typical experiment, we might find something like this: A door can be made to close gently by exerting the following forces for the time intervals shown below.

	Force (F)	Interval of Time of Force Action (Δt)
Case 1.	6 nt	0.1 sec
Case 2.	3 nt	0.2 sec
Case 3.	1 nt	0.6 sec
Case 4.	0.5 nt	1.2 sec

Since these two factors produce an identical effect in each case, we should like to perform an operation on each pair so that we obtain an identical answer in each case.

Which of these will do this?

(2)

A Adding the F value to the corresponding Δt value.

B Multiplying the F value by the corresponding Δt value.

C Dividing the F value by the corresponding Δt value.

YOUR ANSWER --- D

Almost, but not quite.

You seem to have remembered that impulse = change of momentum because you have shown the impulse to have the same numerical value as the change of momentum of the ball and have used the correct units for impulse.

But in your thinking, you did not take the vector nature of these quantities into account. The momentum is decreasing as the ball rises, is it not? We must distinguish between increasing and decreasing vector quantities by using positive and negative signs. Normally, a positive sign is given to an increasing momentum, while a negative sign precedes the numerical value of a decreasing momentum.

Thus, $\Delta p = -1.5$ kg-m/sec. Hence, what is the impulse that stopped the ball?

Please return to page 130 and select the right answer.

YOUR ANSWER --- B

You have ignored notebook entry 3(d)2. How much would you have to add to 15 m/sec to get a result of 8 m/sec?

Please check this before returning to page 144 and selecting the other answer.

YOUR ANSWER --- B

Although we said that we would not emphasize units too heavily for the remainder of this lesson, we do insist that you associate the right units with the answer. Your error here is that you have assigned units of impulse to the momentum of the ball.

Please return to page 147. Be careful with your choice of units.

YOUR ANSWER --- C

We believe that you are being bothered by the fact that the collision of freight cars is an inelastic one where the bodies couple together after impact and move off together. You are probably wondering if the Principle of Conservation of Momentum applies equally well to inelastic collisions as it does to the elastic type exemplified by the billiard balls.

Read through notebook entry 4(b) again. Note that it does not specify any particular type of interaction. The principal requirement is that the system be isolated with no unbalanced, external forces acting on it. Thus, the conservation principle applies just as well to the freight-car collision type of interaction as it does to the type represented by the colliding billiard balls.

Please return to page 103 and pick the right answer.

YOUR ANSWER --- C

Possibly you were being a little too cautious in choosing this answer. It would be contrary to our reason and experience to expect the speeds of the two masses to be different under controlled conditions such as those shown in Figure 3 on page 154. We would first assume that the frictional force acting on both carts are the same; then, if the spring exerts the same force on each cart (in the opposite directions), it would be reasonable even without going any further in our thinking to expect the speeds of the carts to be the same at the instant that the spring drops away.

Please return to page 154 and choose a better answer.

YOUR ANSWER --- D

You are correct. The total change of velocity, taking into account the fact that the new motion is opposite in direction to the old, is the sum:

$$-15 \text{ m/sec} + (-6 \text{ m/sec}) = -21 \text{ m/sec}$$

Before continuing, please turn to page 158 in the blue appendix.

A certain bit of common sense must be applied to the solution of problems involving vectors like impulse and momentum. You simply cannot blindly substitute in formulas or manipulate numbers willy-nilly without reasoning about what you are doing. Formulas alone are only tools to help you.

NOTEBOOK ENTRY
Lesson 11

(Item 3)

(e) When an impulse is large enough to stop a moving body and then reverse its direction, the total change of velocity is the negative sum of the initial velocity and the final velocity.

Example: An object has an initial velocity of 10 m/sec to the north. If it is acted on by a constant force for a long enough time to cause its velocity to change to 8 m/sec to the south, then its change of velocity $\Delta v = -18$ m/sec.

This idea is further expanded in the following problem: An object with a mass of 10 kg moves at a constant velocity of 10 m/sec. A constant force then acts on the object for 4.0 sec, giving it a velocity of 2.0 m/sec in the opposite direction. Now you are going to be asked three questions on this problem. Here is the first one: What is the impulse acting on the object? (Copy this problem in your Notebook.)

(21)

A -120 nt-sec

B -80 nt-sec

C 120 nt-sec

YOUR ANSWER --- C

You are correct. As a matter of fact, it might not go into either! It would depend on the direction in which the impulse is applied to the ball.

Now, on the basis of the information you have been given, would you say that impulse is a scalar or a vector quantity?

Write your answer; then turn to page 115 to check it.

YOUR ANSWER --- D

Getting back to fundamentals, we might start by saying that there is one and only one velocity before the collision--that of the empty freight car v_1; similarly, after impact there is only one velocity, that is the velocity of the coupled cars v_3. The mass of the empty freight car is comparatively small, so let's designate it as just plain little m; its velocity is v_1; hence its momentum is mv_1. O.K.? Hold this for a moment now.

After the collision, the mass is much greater since the empty and loaded cars have coupled together. Let's call this M. The velocity of this combination has been designated as v_3, so the momentum after the collision may be written as Mv_3.

Now, according to the Principle of Conservation of Momentum, what must be true of the two momenta?

(36)

A They are not equal to each other.

B They are equal to each other.

YOUR ANSWER --- C

Why d?

Consistency of symbolization is extremely important in any discussion or study, particularly in physics. The symbol d has represented distance or displacement all along in our work. So the definition you chose defines acceleration as the rate of change of distance with respect to time. This defines speed, not acceleration.

Please return to page 6 and select an answer that really defines acceleration in the most general terms.

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YOUR ANSWER --- B

You are correct. By definition, impulse = $\vec{F}\Delta t$.

So we have: $\vec{F}\Delta t = m\Delta v$

Or, if you like: impulse = $m\Delta v$

(Note: This is an identity, not a defining equation. Impulse is always defined as $\vec{F}\Delta t$.)

Now observe the right side of the equation. Here we have a product of <u>mass</u> and <u>change of velocity</u>. Think carefully. What does $m\Delta v$ represent?

(13)

A Momentum in a slightly different form.

B A change of momentum.

C A change of mass and velocity.

D I don't know.

YOUR ANSWER --- C

This is incorrect. One of the other answers is the right one.

To determine the units for a derived quantity such as impulse, it is always a good idea to substitute the fundamental units in the equation that defines the derived unit.

That is:

$$\text{impulse} = F\Delta t$$

$$\text{So impulse units} = \text{nt} \times \text{sec}$$

The unit for impulse appears to be, therefore, the product of newtons and seconds. Which of the answers given expresses this product?

Please return to page 72 and choose the correct answer.

YOUR ANSWER --- A

You formed the product $m\vec{v}$ properly, but one of the basic units you used does not belong in the MKS system. Remember that MKS stands for meter-kilogram-seconds. You should be able to spot it easily.

Please return to page 153. You should be able to choose the right answer without difficulty.

YOUR ANSWER --- D

We think we know where your difficulty lies; very likely you are puzzled by the presence of the "Δ" between two variables.

If a force is applied to a given mass, the mass must accelerate. Of course, the force must be unbalanced. When a mass is accelerated, its velocity changes, but its mass does not. However, since the momentum of a body is given by $m\vec{v}$, a change of velocity must result in a change of momentum. If we symbolized such a change of momentum as:

$$\Delta m\vec{v}$$

by placing the delta before the product rather than the velocity, this would imply that either or both m and v might change with an unbalanced force. But this is not what happens. The mass remains the same, and only the velocity changes. Thus, we are saying what we really mean by inserting the "Δ" between the m and the v.

Please return to page 46 and select the right answer.

YOUR ANSWER --- A

You are correct. The conservation equation can be solved to show that the recoil velocity of the rifle is inversely proportional to its mass as you clearly realized in choosing the above answer.

An understanding of the application of the Principle of Conservation of momentum to elastic collisions has been instrumental in leading to several important discoveries in atomic and nuclear physics. The subject of collisions and momentum interchange has many complex aspects, but we shall confine our discussion to the simplest considerations.

When two steel balls or billiard balls collide, we have a close approach to the type of collision which occurs on the sub-atomic level. You may have seen the conditions shown in Figure 5 actually occur on a billiard table. Cue ball m_1, moving with a certain velocity v_1, collides head-on (not glancing) with ball m_2. The situation is shown in the left diagram of Figure 5, labeled "Before Impact."

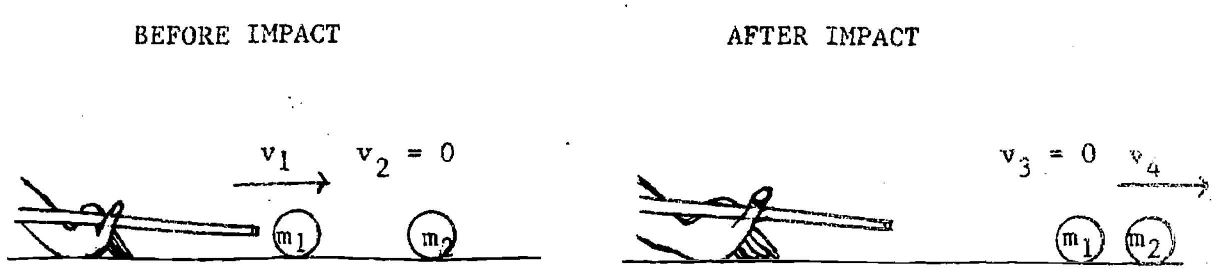

Figure 5

According to the notations on the diagram, what can you say about m_2?

(30)

A Ball m_2 is moving toward m_1 at the time of impact.

B Ball m_2 is moving away from m_1 at the time of impact.

C Ball m_2 is at rest with respect to the table at the time of impact.

YOUR ANSWER --- A

You are quite correct. After the collision, the new mass is the sum of the two original ones, since the cars couple to form a single mass. Hence the velocity after impact must be smaller if the momenta are to be the same.

Thus, in the equation:

$$v_3 = \frac{m_1 v_1}{m_1 + m_2}$$

v_3 must be smaller than v_1. If it comes out equal to v_1 or larger than v_1, you will know immediately that you have erred somewhere.

Referring to the data you copied, you may now substitute the known values in the equation and determine the magnitude of the velocity after impact, v_3. Look over the answers given below; which one do you select as the correct one?

(37)

A 1.0 m/sec

B 1.5 m/sec

C 2.5 m/sec

D None of these answers is correct.

YOUR ANSWER --- A

No, you've missed the point.

If the moving object had merely been brought to rest by the retarding impulse, its change of velocity would have been numerically equal to 15 m/sec. Here, it has not only been brought to rest but also accelerated to a new velocity of 6 m/sec in the opposite direction. This means that, numerically, its velocity must have changed by an amount greater than 15 m/sec. You must remember that velocity is a vector quantity and must not be thought of as merely a certain number of meters per second.

If the initial velocity is taken as 15 m/sec, the impulse required to stop it would be -15 m/sec. If the body is then given an impulse which gives it a new velocity opposite to the original direction, what will be the total change in velocity?

Please return to page 77. Choose an answer that takes into account the directions of the initial and final velocities.

YOUR ANSWER --- C

This doesn't follow from our reasoning.

Momentum means quantity of motion. We have agreed that the quantity of motion possessed by a given body in motion is dependent upon its mass and its velocity. Thus, to cause an increase in momentum, you must increase either the mass or the velocity or both.

If, then, we have somehow increased the momentum of the locomotive, we must have increased either its mass, its velocity, or both. If the mass has been increased, then the engine will have more inertia. It will be more difficult for the wood stop to bring it to rest. Therefore, it seems reasonable that the probe will have to penetrate more deeply into the wood stop before enough retarding force can be brought to bear on the locomotive to stop its motion.

On the other hand, if the momentum has been increased by raising the rolling speed, then a given force will need more time to decelerate the locomotive to rest. Again, this implies that the probe will have to penetrate more deeply in order to do the job of stopping the engine.

Please return to page 7 and read the question again. You should be able to select the right answer now.

CORRECT ANSWER: In its most general terms, the equation should look something like this:

$$m_1v_1 + m_2v_2 = m_1v_3 + m_2v_4$$

in which:

m_1 = mass of bullet
v_1 = velocity of bullet before impact
m_2 = mass of block
v_2 = velocity of block before impact
v_3 = velocity of bullet after impact
v_4 = velocity of block after impact

Well, let's see. Since the bullet becomes embedded in the block and brings it to rest, then both v_3 and v_4 must be zero. In the equation above, then, which terms become zero and drop out.

(38)

A m_1v_1 and m_1v_3.

B m_1v_3 only.

C m_2v_4 and m_1v_3.

D m_1v_3 and m_2v_2.

YOUR ANSWER --- C

This statement is quite true, but it doesn't answer the question. At the instant the powder explodes, the rifle begins to move toward the south. When the bullet leaves the muzzle, the rifle is moving at a speed of 1.4 m/sec. The marksman's shoulder may prevent it from going very far, thus retarding the recoil action, but this does not explain why the rifle would have had a speed of only 1.4 m/sec even if the shoulder were not there.

Please return to page 127 and choose a better answer.

YOUR ANSWER --- B

Good. You're going along with the accepted convention that a velocity to the right is (+) and a velocity to the left is (-).

All right, let's substitute the known values from Figure 7 on page 113 in the equation:

$$v_1 = \frac{-m_2 v_2}{m_1}$$

and solve for v_1. Select one of the answers below to verify your results.

(40)

A -1,000 m/sec

B 100 m/sec

C 1,000 m/sec

D None of these answers.

YOUR ANSWER --- C

This is not the right equation.

The symbol for momentum is p. If you solve the equation v = mp for p, you get:

$$p = \frac{v}{m}$$

But we decided that momentum is a product, not a quotient; hence this equation is incorrect.

Please return to page 141 and select the right answer.

YOUR ANSWER --- B

If doubling either m or v alone causes the quantity of motion to double, then the quantity of motion must be directly proportional to both these quantities:

$$\text{quantity of motion} = kmv$$

Although this proportionality statement was arrived at in a more or less intuitive fashion, it can be handled just like any other proportion. (Of course, it must be subjected to mathematical and experimental tests before it is accepted fully.) If you substitute 2m for m and 2v for v, indicating that both quantities have been doubled, what then happens to the quantity of motion?

Please return to page 83 and pick the answer that meets the terms of the problem.

YOUR ANSWER --- A

The decimal point in this answer is misplaced.

You should train yourself to inspect the numerical form of the equation after substitution in every problem you do so as to establish the anticipated order of magnitude of the answer. In this case:

$$\Delta t = \frac{0.50 \times (-3.0)}{-0.50 \times 9.8} \text{ sec}$$

Merely inspecting this visually should tell you that the 0.50 factor in the numerator will be canceled by the 0.50 factor in the denominator, leaving you with:

$$\Delta t = \frac{-3.0}{-9.8} \text{ sec}$$

Since this is approximately 1/3 sec, you know at once that an answer of 3.1 sec is not possible.

Please return to page 125 and select another answer.

YOUR ANSWER --- A

You are correct. The straightforward solution goes like this:

$$v_3 = \frac{m_1 v_1}{m_1 + m_2}$$

$$v_3 = \frac{(6.0 \times 10^4) \times 3.0}{(6.0 \times 10^4) + (1.2 \times 10^5)}$$

In order to add the terms in the denominator, we must equalize the exponents of the powers-of-ten. Let's change 1.2×10^5 to 12.0×10^4. Then:

$$v_3 = \frac{(6.0 \times 10^4) \times 3.0}{(6.0 \times 10^4) + (12.0 \times 10^4)}$$

$$v_3 = \frac{18 \times 10^4}{18 \times 10^4} = 1.0 \text{ m/sec}$$

If you were very alert, you might have been able to predict this answer without going through the straightforward solution. Since the loaded freight car has twice the mass of the empty one, when they are coupled, the total mass is exactly 3 times as large as the mass of the empty freight car. Thus, the velocity after impact would have to be 1/3 of the original velocity. Since the original velocity v_1 = 3.0 m/sec, then v_3 would have to be 1.0 m/sec.

Now, here's a similar problem for you to work out alone.

A boy having a mass of 60 kg steps vertically into a 75 kg canoe that is moving at a speed of 1.0 m/sec. What is the speed of the canoe after he steps aboard? (Copy all the data before starting your solution.) Write your answer, please, before you turn to page 113 to check your work.

YOUR ANSWER --- C

You are correct. This expression states two important details distinctly: (1) The change of momentum of one interacting body is the same as the change of momentum of the other interacting body; and (2) the direction of the momentum change for one body is opposite that of the other.

This leads directly to one of the most important principles in all of physics. It is called the Principle of Conservation of Momentum. Let's state it as a notebook entry.

NOTEBOOK ENTRY
Lesson 11

4. The Principle of Conservation of Momentum

(a) Statement 1: Whenever the momentum of one body is changed, the momentum of some other object must change also by exactly the same amount and in the opposite direction.

(b) Statement 2: In an isolated system of masses (no unbalanced external force acting on the system) the total momentum of the system is conserved (remains unchanged) regardless of the number of interactions that may occur.

(c) Symbolic statement: $m_1\Delta v_1 = -m_2\Delta v_2$

An excellent example of an isolated system is provided by the firing of a bullet from a rifle. Before the powder explodes, both bullet and rifle are at rest; there are no external forces acting on either of the two except for gravity which, in this case, is balanced out by the arm holding the rifle. Suppose the bullet is fired horizontally due north; according to Statement 1 above, the bullet will have a specific momentum toward the north while the ________ will have exactly the same momentum toward the south. What is the missing word.

Please turn to page 127.

YOUR ANSWER --- B

Refer to Figure 3 on page 154.

You will agree that when the cord is burned, mass m_1 will move off to the left and mass m_2 will be driven to the right. If two velocities have different directions, can they possibly be exactly the same? You must constantly think in terms of vectors. The magnitudes of the velocities might very well be equal, but if their directions are different, then the velocities are very definitely not the same.

Please return to page 154 and select a better answer.

YOUR ANSWER --- A

Are you saying that a punch delivers a smaller force than a gentle push with the finger? A punch is a hard, sharp blow; a considerable force is exerted on the body that receives it.

How about the <u>time</u> of action of a punch compared to a push? When you push something, does your hand remain in contact with the object being pushed for a longer or shorter time than when you <u>punch</u> it?

Please return to page 4 and find a better answer.

YOUR ANSWER --- B

To determine the units for a derived quantity such as impulse, it is always a good idea to substitute the fundamental units in the equation that defines the derived unit.

That is:

$$\text{impulse} = F\Delta t$$

$$\text{So impulse units} = \text{nt} \times \text{sec}$$

The unit for impulse appears to be, therefore, the product of newtons and seconds. Would this be newtons <u>per</u> second?

Please return to page 72. The answer should be easy for you now.

YOUR ANSWER --- C

You are correct.

$$v_1 = \frac{m_2 v_2}{m_1} = \frac{2.0 \text{ kg} \times (-3.0 \text{ m/sec})}{0.006 \text{ kg}}$$

$$v_1 = \underline{1{,}000} \ \underline{\text{m/sec}}$$

Please turn to page 160 in the blue appendix.

YOUR ANSWER --- A

It is true that v_1 is larger than v_2, but not because the cars couple together at impact.

The problem states that v_1 (the velocity of the empty freight car before impact) is 3 m/sec and that v_2 (the velocity of the loaded freight car before impact) is zero. So it is quite true that v_1 is larger than v_2, but this is simply one of the stated conditions of the problem.

Please return to page 88. Look over the other answer carefully before making another selection.

CORRECT SOLUTION:

$$\Delta t = \frac{m\Delta v}{F}$$

The mass of the ball is 0.50 kg. The velocity of the ball is decreasing; hence Δv is a negative quantity, i.e., -3.0 m/sec.

Now, what is F? Since the ball is being stopped by gravitational attraction, the F is the force of gravity acting on the ball, or, in other words, the weight of the ball.

We know the mass of the ball is 0.50 kg. Now how much does the ball weigh?

(17)

A 0.50 nt

B 0.50 x 9.8 nt

C $\frac{0.50}{9.8}$ nt

YOUR ANSWER --- B

There are some improper associations in this equation. You can see by referring to Figure 5 on page 50 that mass m_2 is not associated with velocity v_3 at any time during the interaction; similarly m_1 is not associated with v_4, either.

It is always important in momentum problems to carefully make sure that the velocity associated with a given mass is the correct one.

Please return to page 13 and choose a better answer.

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YOUR ANSWER --- B

You are correct. The freight cars form an isolated system; there are no horizontal external forces acting on either car from the outside; hence the system must follow the Principle of Conservation of Momentum.

Then, if the two momenta are equal to each other, we may write symbolically:

$$mv_1 = Mv_3$$

where m is a small mass and M is a large mass, and where we are to predict the relative magnitudes of the velocities v_1 and v_3.

Here we have two products that are equal as a result of the workings of the conservation principle. Taking some simple numbers to illustrate our point, suppose m, the small mass, is 2 kg and M, the large mass, is 10 kg. Suppose further that v_1 is 20 m/sec, and you want to find the relative magnitude of v_3. Substituting:

in $m \times v_1 = M \times v_3$, we obtain

$$2 \times 20 = 10 \times ?$$

What value would v_3 have to have in this simple example? Write your answer; then please turn to page 126.

YOUR ANSWER --- A

Precisely what does that mean?

When one speaks of the "negativeness" or the "positiveness" of a physical quantity, he always does so on a comparative basis. Something is negative with respect to something else; the word negative has no meaning if applied in isolation to the description of a force, a velocity, an impulse, or any other quantity.

So, in itself, the notion of a negative or a positive force doesn't tell us anything. Please select the answer that tells us to what this "negativeness" is related.

Please return to page 143 and try to select it.

YOUR ANSWER --- B

You are correct. Here it is:

F		Δt		Result
6	x	0.1	=	0.6
3	x	0.2	=	0.6
1	x	0.6	=	0.6
0.5	x	1.2	=	0.6

So, impulse may be defined as the product of a force times the interval of time over which it acts. That is:

$$\text{impulse} = F\Delta t$$

In the MKS system, force is measured in newtons and time is measured in seconds. Since impulse = $F\Delta t$, what is the proper unit in the MKS system for the impulse of a force?

(3)

A Newton-seconds (nt-sec).

B Newtons per second (nt/sec).

C Neither of the above answers.

YOUR ANSWER --- A

Have you forgotten what you started out to find? Your listing of data for this problem should tell you what you are required to determine. We must conclude that you didn't copy it as you were requested.

Please return to page 88 to review and copy the listing.

YOUR ANSWER --- C

No, they would not be the same. If m_2 is made larger than m_1, its inertia would be greater. This means that if the same force is applied to both m_1 and m_2, the larger mass would accelerate more slowly than the smaller one. Since the force acts on both masses for the same time, and if the acceleration of one mass is greater than the other, can their speeds be the same after the spring has fallen away?

Please return to page 23 and select a better answer.

YOUR ANSWER --- C

You are correct. Since both v_3 (velocity of bullet after impact) and v_4 (velocity of block after impact) are both zero, then any product in which either appears must be zero.

In that case, the equation becomes:

$$m_1v_1 + m_2v_2 = 0$$

Now, since we want the velocity of the bullet before impact, we should solve this equation for v_1. That is:

$$m_1v_1 = -m_2v_2$$

$$v_1 = -\frac{m_2v_2}{m_1}$$

We have this data:

$m_1 = 0.0060$ kg $m_2 = 2.0$ kg

What is the velocity of the wood block before the collision occurs?

(39)

A 3.0 m/sec

B -3.0 m/sec

YOUR ANSWER --- C

What happened? This is not correct.

We have just defined acceleration as the change of velocity with respect to time. How, then, can you define the same quantity as the product of force and time? You can't, of course.

Please return to page 122. If you must, check your notes before selecting the answer again.

YOUR ANSWER --- A

You are correct. The velocity decreases; hence the numerical value for Δv is a minus quantity.

Let's go a little farther with this. Again take the initial uniform velocity of the body as 15 m/sec to the right. If the impulse acting on it is great enough, the body will be brought to rest. Clearly, the change of velocity in this case is $\Delta v = -15$ m/sec, the minus sign being required to show that the velocity has decreased.

As our last step, consider the condition where the impulse is so large that it not only brings the body to rest but also causes it to reverse direction and pick up some speed <u>to the left</u>. For example, suppose that the initial velocity is 15 m/sec to the right and that the impulse acts toward the left, causing the body to stop and then begin moving toward the left with a velocity of 6 m/sec. Now note that the moving object has first decelerated to a stop and then has accelerated to a final velocity in the opposite direction.

What value would you assign to Δv in this situation?

(20)

A $\Delta v = 9$ m/sec

B $\Delta v = -9$ m/sec

C $\Delta v = 21$ m/sec

D $\Delta v = -21$ m/sec

YOUR ANSWER --- C

This answer is incorrect on several counts. (Refer to Figure 5 on page 50.) First of all, it ignores the fact that velocities v_2 and v_3 must be taken into account in any calculation of total momentum.

Secondly, this equation associates m_1 with v_4. This mass and velocity do not belong together; they are not associated with each other.

Improper association of symbols is a common source of error in momentum discussions and calculations. It pays to be careful.

Please return to page 13 and choose a better answer.

You have now completed the study portion of Lesson 11 and your Study Guide Computer Card and A V Computer Card should be properly punched in accordance with your performance in this Lesson.

You should now proceed to complete your homework reading and problem assignment. The problem solutions must be clearly written out on 8½" x 11" ruled, white paper, and then submitted with your name, date, and identification number. Your instructor will grade your problem work in terms of an objective preselected scale on a Problem Evaluation Computer Card and add this result to your computer profile.

You are eligible for the Post Test for this Lesson only after your homework problem solutions have been submitted. You may then request the Post Test which is to be answered on a Post Test Computer Card.

Upon completion of the Post Test, you may prepare for the next Lesson by requesting the appropriate

1. study guide
2. program control matrix
3. set of computer cards for the lesson
4. audio tape

If films or other visual aids are needed for this lesson, you will be so informed when you reach the point where they are required. Requisition these aids as you reach them.

Good Luck!

YOUR ANSWER --- A

You are correct. In formal terms:

$$p_o = mv_o$$

(The zero subscript indicates, as usual, initial conditions.)

$$p_o = 0.50 \text{ kg} \times 3.0 \text{ m/sec} = 1.5 \text{ kg-m/sec}$$

And since the velocity is a vector quantity directed upward, then the momentum is directed upward as well.

Another question about the same ball: What is the momentum of the ball at the highest point in its upward flight? This is an easy question, so we'll omit the choices. Write your answer; then turn to page 130.

YOUR ANSWER --- A

You are correct. Both the boy and the man start from rest. Their individual changes of momentum are the same as their individual final momenta. We'll calculate the change of momentum for each and compare them. Let us designate a velocity to the right as (+) and a velocity to the left as (-). This is a purely arbitrary choice of vector directions and could just as well have been the other way around without making any difference in the analysis.

Man: $\Delta p_m = m_m \Delta v_m = 80 \text{ kg} \times 0.25 \text{ m/sec} = 20 \text{ kg-m/sec}$

Boy: $\Delta p_b = m_b \Delta v_b = 50 \text{ kg} \times (-0.40 \text{ m/sec}) = -20 \text{ kg-m/sec}$

Despite the differences in mass and velocity, the changes of momentum have the same magnitude. Any experiment we do under these same conditions works out the same way: The interacting bodies, provided that no external forces are applied, separate with the same momenta in opposite directions.

This relationship may be conveniently expressed in symbolic form. Which of the following is the best expression of the ideas we have just discussed?

(27)

A $m_1 \Delta v_1 = m_2 \Delta v_2$

B $\Delta m_1 v_1 = -\Delta m_2 v_2$

C $m_1 \Delta v_1 = -m_2 \Delta v_2$

YOUR ANSWER --- B

We have seen that there is an inverse relationship between velocity and mass in an explosion-type of action. That is:

$$\Delta v_r = -\Delta v_b \times \frac{m_b}{m_r}$$

In the case of the second rifle, we are using the same bullet; hence v_b and m_b remain the same. Since these quantities do not change, why not think of them as comprising a constant k which may be substituted in their place so that we can write:

$$\Delta v_r = -\frac{k}{m_r}$$

This expression, then, is easy to interpret. The change of velocity of the rifle is inversely proportional to its mass. Thus, the new rifle took on a speed that was 4 times as great as that of the original rifle. Can its mass be 4 times that of the original rifle?

Please return to page 100. You should have no difficulty now.

YOUR ANSWER --- B

You are correct. You changed 0.005 min to 0.30 sec and then found the impulse as the product of 80 nt x 0.30 sec = 24 nt-sec.

Just for a while, we shall leave the subject of impulse and investigate the characteristic of a moving mass that Newton called its quantity of motion. This idea was briefly discussed in the introduction to this lesson. If a mass m moves with a velocity v, we sense that there is a certain quantity of motion; when we double the mass (2m) while it has the same velocity as before, we feel intuitively that the quantity of motion has also doubled. Now going back to the single mass m, suppose we double the velocity; again we sense that this, too, should double the quantity of motion. So, if either the mass or the velocity is doubled, the quantity of motion doubles.

What do you think happens to the quantity of motion if we double both the mass (2m) and the velocity (2v)?

(6)

A Doubling both causes a cancellation which makes the quantity of motion the same as it was for mass m and velocity v.

B Doubling both m and v causes the quantity of motion to double.

C Doubling both m and v causes the quantity of motion to be 4 times as great as it was.

YOUR ANSWER --- B

You are correct. Momentum is the product of mass and velocity.

Before going further, we must decide whether or not momentum is a scalar or vector quantity. In discussing impulse, you noted that when a vector quantity is multiplied (or divided) by a scalar quantity, then the product (or quotient) is a vector quantity.

Therefore without further ado, we can say the momentum p is a vector quantity. The reason for this statement stems from the fact that p is the product of which quantities?

(9)

A Mass (vector) x velocity (scalar).

B Mass (vector) x velocity (vector).

C Mass (scalar) x velocity (vector).

YOUR ANSWER --- C

You are correct. We are to find the velocity of the coupled cars after impact.

After simplifying, we came out with this equation:

$$m_1 v_1 = v_3(m_1 + m_2)$$

Solving for v_3, we have:

$$v_3 = \frac{m_1 v_1}{m_1 + m_2}$$

Now, before substituting in this expression, to avoid getting lost in a morass of numbers, let's look ahead to the physics of the problem. Would you expect the common velocity of the coupled car to turn out to be larger, smaller, or the same as the velocity of the empty freight car before impact? In short, by anticipating in this fashion you can tell whether the answer you get for v_3 contains a possible blunder.

(35)

A v_3 should be smaller than v_1.

B v_3 should be larger than v_1.

C v_3 should be equal to v_1.

D I don't know how to predict this.

YOUR ANSWER - - A

Not true. It is true that v_3 is zero, making the second term zero, but v_1, the velocity of the bullet, is a finite quantity, not zero. Hence the product m_1v_1 cannot be zero.

Read the question again after returning to page 54; then please pick another answer with care.

YOUR ANSWER --- B

In the set of conventions we are following, a (-) sign before the numerical value of the force is presumed to indicate that the force is one that retards the motion or causes deceleration. When a force is applied in the same direction as the initial motion of the body, would this retard or accelerate the body positively?

Please return to page 143. There is a much better answer you can choose.

YOUR ANSWER --- A

You are correct. The Principle of Conservation of Momentum applies to any type of interaction or collision. So, although the freight car collision is inelastic, momentum must be conserved.

Let us write the general equation first, using the same notation as for the billiard balls:

$$m_1v_1 + m_2v_2 = m_1v_3 + m_2v_4$$

Next, we'll list the quantities we know.

m_1 = mass of empty freight car (6.0×10^4 kg)
v_1 = velocity of empty freight car before impact (3 m/sec)
m_2 = mass of loaded freight car (1.2×10^5 kg)
v_2 = velocity of loaded freight car before impact (0 m/sec)
v_3 = velocity of empty freight car after impact (?)
v_4 = velocity of loaded freight car after impact (?)
(Copy the above listing.)

Since the cars couple together at impact, this means that which of the following must be true?

(33)

A v_1 must be larger than v_2.

B v_3 must be larger than v_4.

C v_3 must be equal to v_4.

D v_3 must be less than v_4.

YOUR ANSWER --- C

You made a creditable stab at it, but you lost your way!

From Newton's Second Law, we know that:

$$w = mg$$

You want the weight w of the ball. You know the mass m and the value of g close to the Earth. Apparently, you inverted the equation somehow in selecting this answer.

Return to the original question, please, by turning to page 67. Choose the right answer this time.

This page has been inserted to maintain continuity of text. It is not intended to convey lesson information.

YOUR ANSWER --- B

This answer is incorrect.

We think we know how you reasoned to arrive at this answer. You probably noticed that the mass of the loaded freight car is exactly twice that of the empty one since the masses are, respectively:

loaded car	1.2×10^5 kg
empty car	6.0×10^4 kg

Thus:

$$\frac{1.2 \times 10^5}{6.0 \times 10^4} = 0.20 \times 10^1 = \underline{2.0}$$

So you then reasoned that if the loaded car is twice as massive as the empty one, the velocity after impact must be half the velocity before impact. The velocity before impact, v_1, is 3.0 m/sec, and half of that is 1.5 m/sec.

Where is the error in your reasoning? It's easy! The mass after impact is not twice that before impact. Study the terms of the problem again; you will see why we say this. What happened to the cars at the moment of impact?

Please return to page 51. Choose the correct answer.

YOUR ANSWER --- C

You evidently formed a product to obtain the derived units, but you have used the wrong unit for velocity.

Once you determine why we say that you've used the wrong velocity unit, you should have no trouble in selecting the proper answer. Please return to page 153.

CORRECT ANSWER: Since v_2 and v_3 are both zero, then m_2v_2 and m_1v_3 drop out, leaving the simplified expression:

$$m_1v_1 = m_2v_4$$

Note that we have been omitting vector arrows for simplicity. Also, since v_1 and v_4 have the same direction both are considered (+) quantities in this example.

We can assume without the danger of significant error that the billiard balls of our example in Figure 5 on page 50 are of equal mass. Basing your thinking on this assumption, you can then answer the following question: If the first billiard ball strikes the second at 1.8 m/sec, with what speed will the second billiard ball move after impact?

Write your answer to this question and then turn to page 103 for confirmation.

YOUR ANSWER --- B

You are correct. Good thinking! When an unbalanced force is applied to a mass, the velocity of the mass must change either in magnitude or direction. This change of velocity is symbolized by Δv. But when the velocity of a mass changes, then its momentum must also change. Thus, $m\Delta v$ tells you that the momentum has changed. Obviously, we don't write it this way: $\Delta m\vec{v}$, because this might give the false impression that mass was changing. For a given body, the mass is constant.

Before continuing, please turn to page 157 in the blue appendix

We have progressed to this point: $\vec{F}\Delta t = m\Delta v$

We can now interpret it correctly.

NOTEBOOK ENTRY
Lesson 11

3. Relationship of impulse and momentum

(a) Newton's Second Law may be used to show that: $\vec{F}\Delta t = m\Delta v$

(b) This equation states that the impulse of a force applied to a mass is equal to the change of momentum which the mass undergoes as a result of the impulse.

(c) Since both force and velocity are vector quantities, it must be remembered that the complete form of the equation is:

$$\vec{F}\Delta t = m\Delta v$$

As long as you remember the vector nature of these quantities, it is permissible to omit the vector arrows.

Let's consider a simple example. How great is the impulse that gives an 8.00-kg mass a change of velocity of 4.00 m/sec? (Copy this problem into your notebook as an illustrative example.) Work out the answer; then check it by turning to page 31.

YOUR ANSWER --- B

There are actually two errors in this answer.

First, the units given are those of momentum. We want impulse units here.

Second, you have failed to recognize that both impulse and momentum are vector quantities. As the ball rises and finally comes to rest at the top of its flight, its momentum gradually <u>decreases</u> to zero. It is conventional to refer to increasing momentum as a positive quantity and decreasing momentum as a negative quantity.

With these hints, you should have no difficulty in selecting the right answer. Please return to page 130 and do so.

YOUR ANSWER --- A

Look at Figure 5 on page 50 again. Note that the symbol v_2 evidently applies to m_2 just before impact occurs. Since $v_2 = 0$, then m_2 cannot be moving toward m_1, can it? If it were moving at all, it would have a definite velocity one way or the other.

Please return to page 50 and select the right answer.

YOUR ANSWER --- A

Truly, this is not really an error at all. It is merely a matter of talking a common language. Refer to Figure 7 on page 113. If you used 3.0 m/sec instead of -3.0 m/sec in the calculations for this problem, the velocity of the bullet before impact would simply turn out to be a (-) quantity. This would indicate a reversal of the usual convention but would not cause the answer to be in error.

We might understand your choice of this answer if we hadn't also offered -3.0 m/sec. As a matter of consistency, we agreed a long time ago that we would indicate velocities to the right as (+) quantities and velocities to the left as (-) quantities. In this way, we adhere to the conventional axis notation in Cartesian coordinates where the X-axis is (+) to the right and (-) to the left of the origin.

So, let's use the accepted conventions about signs from now on.

Please return to page 75 and choose the alternative answer.

YOUR ANSWER --- B

There is a blunder in the placement of the decimal point in this answer.

One of the things you must train yourself to do is to inspect the numerical combination after substitution to determine the order of magnitude to be expected. In this case:

$$\Delta t = \frac{0.50 \times (-3.0)}{-0.50 \times 9.8} \text{ sec}$$

It should be perfectly evident to you that the 0.50 in the numerator will cancel the same factor in the denominator and leave you with:

$$\Delta t = \frac{-3.0}{-9.8} \text{ sec}$$

Since this is approximately 1/3, how could your answer possibly turn out to be 31 sec?

Please return to page 125 and select a better answer.

YOUR ANSWER --- C

We agree that a punch represents a larger force than a gentle push with a forefinger. But we wonder if you have thought with sufficient care about the time involved in each of these actions. Do you really think that a sharp blow lasts for a longer time than a gentle push used to close a door? You must remember that a sharp blow causes sudden acceleration of the object; the object then moves away from the source of the blow so that the force cannot continue to act on it any longer.

Please return to page 4. The right answer choice should now be quite obvious.

YOUR ANSWER --- B

You are correct. This is easily seen if we solve the conservation equation for the ratio of the velocities by cross-multiplying:

$$m_r \Delta v_r = -m_b \Delta v_b$$

$$\frac{\Delta v_r}{\Delta v_b} = -\frac{m_b}{m_r}$$

This shows that the ratio of the velocity of the rifle to that of the bullet is the same as the ratio of the mass of the bullet to the mass of the rifle. Since the bullet's mass is very small compared to the rifle's mass, the ratio on the right is a very small number, too, and the value of Δv_r is very small compared to the value of Δv_b.

Suppose the same bullet were fired from a different rifle which recoiled with a speed of 5.6 m/sec. Since 5.6 is 4 times as large as 1.4, what would you immediately know about the new rifle?

(29)

A It has ¼ the mass of the original one.

B It has 4 times the mass of the original one.

C It uses a different firing mechanism.

YOUR ANSWER --- B

The definition you selected is often used in calculations under certain very specific conditions. If it is understood that the accelerating body starts from rest, then v may be taken to be the velocity that the body has gained; if the timing process began with $t = 0$, then t may be taken as the interval elapsed while the velocity was increasing from zero to its final value v. Thus, $\vec{a} = \vec{v}/t$ is not a good general definition of acceleration, since it is useful only for a situation involving the specific conditions described.

In general, acceleration is defined as the rate of change of velocity per unit time. A mathematical statement of this definition which is to be applicable to any conditions of initial velocity and any timing range should contain the idea of change. In $\vec{a} = \vec{v}/t$, there is no indication of anything changing.

Please return to page 6. You should be able to pick the best answer at this point.

YOUR ANSWER --- B

We hoped that we had cleared this point up before.

When the delta precedes the product, there is an implication that the momentum may change as a result of a change in either the mass or the velocity of the body, or both. However, since our problem involves one specific body for m_1 and one body for m_2, the mass is not a variable. Hence, the mathematical expression should not permit this to be considered as a possibility.

Please return to page 81. You should be able to pick the right answer now.

CORRECT ANSWER: The second billiard ball will move off at a speed of 1.8 m/sec, too. Clearly, if $m_1v_1 = m_2v_4$, and in addition if $m_1 = m_2$, then we can see at once that $v_1 = v_4$. Thus, the velocity of the moving ball before impact must equal the velocity of the moving ball after impact.

In the collision of the billiard balls, the momentum of the first ball is completely transferred to the second ball. There is an entirely different type of collision, as exemplified in the problem to follow, which also can be solved through the use of the conservation principle.

However, before continuing, please turn to page 159 in the blue appendix.

Standing on the same track is an empty freight car of mass 6.0×10^4 kg and a loaded car of mass 1.2×10^5 kg (Figure 6). The empty freight car is on an incline with its brakes locked, while the loaded car is on level track with its brakes off. Somehow, the brakes of the freight car 1 are released, and it rolls down the incline, colliding with freight car 2. At the instant of impact, car 1 is moving at a speed of 3 m/sec. At impact, the cars couple together and move off as a unit. What is their common speed after the collision?

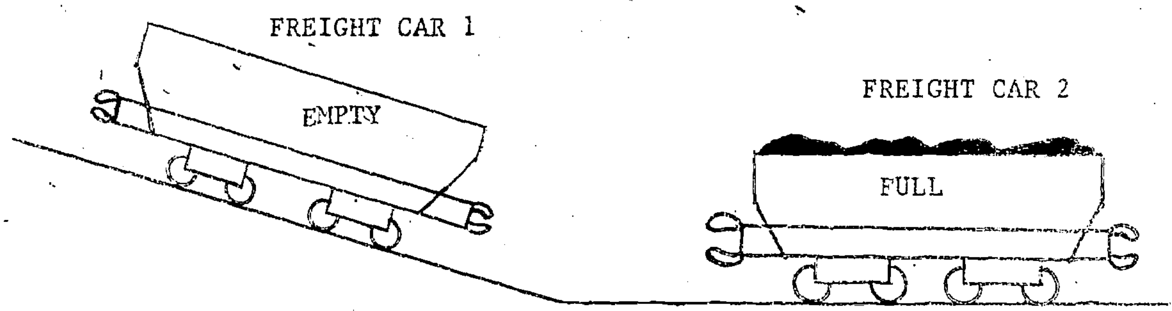

Figure 6

This is called an <u>inelastic collision</u>. It represents an isolated system because no unbalanced external forces act on the cars. Will the total momentum of the system be the same after the collision as it was before?

(32)

A Yes.

B No.

C I don't know.

YOUR ANSWER --- B

If velocity were a scalar quantity, then $\Delta\vec{v}$ could be found by subtracting the final from the initial velocity without regard for the physical conditions implied by the problem. But it is not a scalar and cannot be so handled.

You subtracted 10 m/sec from 2.0 m/sec and obtained a value of -8.0 m/sec for $\Delta\vec{v}$. This is where your error lies. Refer to notebook entry 3(e) to review the reasons that explain why this operation is not satisfactory.

Please return to page 39 and choose a better response.

YOUR ANSWER --- B

It might go into the water hazard if the golfer swings in such a way as to drive the ball to his right. But he could just as well apply the force to his left or straight ahead. What then?

Please return to page 134. Your answer should be thoughtfully chosen.

YOUR ANSWER --- A

This cannot be true if the Principle of Conservation of Momentum is to apply to all interaction situations.

The principle states that in an isolated system of masses (no unbalanced forces acting on the system) the total momentum of the system remains unchanged regardless of the number of interactions that may occur.

Our freight car system is an isolated one. No unbalanced external forces act on the cars during the interaction. (Gravity does act on both but the reaction force upward is opposite and equal to the weight of each car. Thus, the cars are in equilibrium vertically during and after impact, so gravitational force may be ignored.)

So since the system is isolated, and there is an interaction that fits the conservation principle in all its details, the momentum before impact must be exactly the same as the momentum after the collision.

Please return to page 41 and choose the alternative answer.

YOUR ANSWER --- D

This is not correct. The list of answers <u>does</u> contain the correct one.

Please repeat your calculations. Be sure your substitutions are correct, and then watch that decimal point!

Correct your error; then turn to page 56 and choose the right answer.

YOUR ANSWER --- B

You are correct. Mass m_2 has a larger inertia than m_1. With the same force applied by the spring to both masses, the smaller mass would experience the greater acceleration (acceleration varies inversely with mass). Since the force acts for the same time on both masses, then the mass with the greater acceleration would acquire the greater speed.

When two bodies interact as in the previous example, the same or different velocities may be imparted to them by a common force, depending upon their respective masses. It might occur to you to ask whether there is some simple relationship between the momenta (plural for momentum) of the two bodies.

There is, indeed! For example, as shown in Figure 4, the two carts start from rest and, when the cord is burned, m_1 acquires a speed of 2.0 m/sec, while m_2 acquires a speed of 0.20 m/sec. You will observe that m_1 = 0.10 kg and m_2 = 1.0 kg.

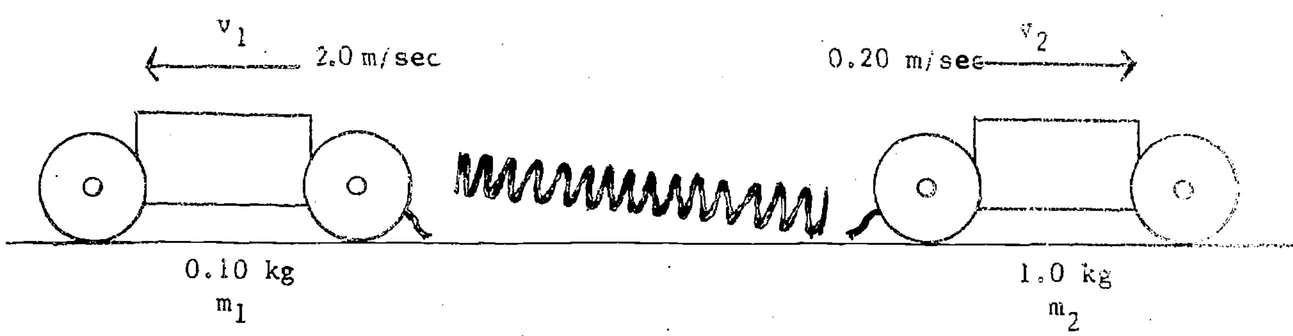

Figure 4

The change of momentum of m_1 as a result of burning the cord is easily explained. Since the mass was initially at rest, its change of momentum is the same as the final momentum acquired, or $\Delta p_1 = m_1 \Delta v_1$ = 0.10 kg x 2.0 m/sec = 0.20 kg-m/sec toward the left. The change of momentum of m_2 is similarly easy to determine.

The change of momentum of m_2 is ______________. Write the full answer; then turn to page 151 to check your answer.

YOUR ANSWER --- B

This answer indicates that you need a review of your notes on vectors and scalars in general.

One or both of the quantities in your answer choice are mislabeled with respect to their vector or scalar nature.

Think about this again, or look up definitions of scalars and vectors

Please return to page 84. Don't guess. Be certain you know which quantity is vector or scalar before choosing another answer.

YOUR ANSWER --- A

Your mind is still back on a previous step of this problem.

You have chosen the change of momentum ($m\Delta v$) as the answer to the question: "What is the momentum after the force acts?" The change of momentum is the difference between the initial momentum and the final momentum and is numerically equal to the impulse. We are looking for the final momentum of the body, not the change it experiences.

Please return to page 26. Select a better answer.

YOUR ANSWER --- B

You didn't read the question with enough care. There is one glaring error in the set of units presented above.

Please return to page 31 and select a better answer.

YOUR ANSWER --- C

You are correct. When the cars couple together, they constitute a single moving body with a single speed. Thus, $v_3 = v_4$.

So, if $v_3 = v_4$, we can simplify the original equation like this:

$$m_1v_1 + m_2v_2 = m_1v_3 + m_2v_4$$

becomes $$m_1v_1 + m_2v_2 = m_1v_3 + m_2v_3, \text{ and then}$$

$$m_1v_1 + m_2v_2 = v_3(m_1 + m_2)$$

Now look at the list of data. You will see that v_2, the velocity of the loaded freight car before impact, is zero. Hence, the term m_2v_2 drops out, and the equation is further simplified to:

$$m_1v_1 = v_3(m_1 + m_2)$$

Of the various factors present in this simplified form, which one is the unknown in this problem?

(34)

A m_1

B v_1

C v_3

D m_2

CORRECT ANSWER: The speed of the canoe after the boy steps aboard is 0.56 m/sec.

The solution:

m_1 = mass of canoe = 75 kg
m_2 = mass of boy = 60 kg
v_1 = initial velocity of canoe = 1.0 m/sec
v_3 = velocity of boy and canoe after boy steps vertically into canoe

The equation:

$$v_3 = \frac{m_1 v_1}{m_1 + m_2}$$

Substitution:

$$v_3 = \frac{75\text{ kg} \times 1.0\text{ m/sec}}{75\text{ kg} + 60\text{ kg}}$$

$$v_3 = \frac{75\ \cancel{\text{kg}}\text{-m/sec}}{135\ \cancel{\text{kg}}} = 0.56\text{ m/sec}$$

In this problem and in the preceding one, the conditions were set up so that a moving object collided with an object at rest, the result being that the two objects moved off together at the same velocity.

Just for the fun of it, let us work out a problem together in which both objects are in motion when an inelastic collision between them occurs. Refer to Figure 7. A 6-gram bullet (0.0060 kg) is fired toward the right into a 2.0-kg wood block that is moving toward the left along a frictionless table at 3.0 m/sec. The bullet penetrates part-way into the block, bringing it to a complete stop. We want to find the velocity of the bullet. Write a conservation equation in very general terms that fits this situation.

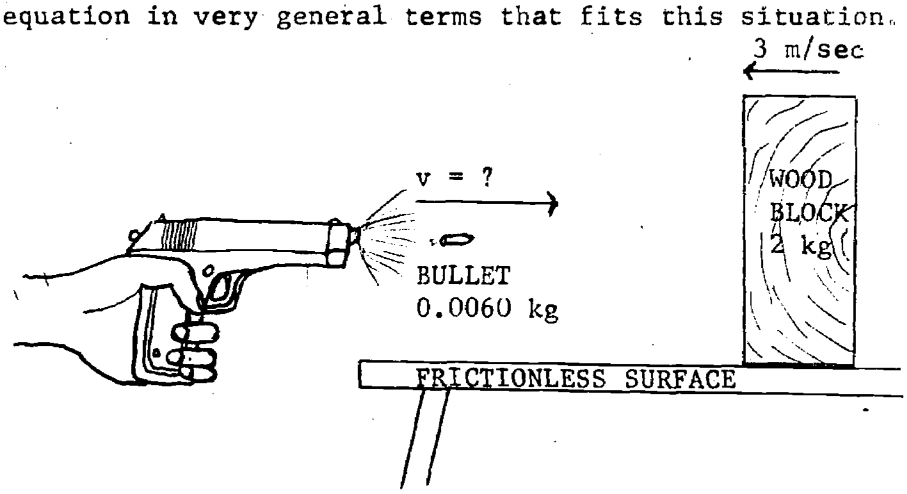

Figure 7

After you have written the equation, please turn to page 54.

YOUR ANSWER --- A

What does the expression you selected tell you?

It states that the change of momentum of mass m_1 is equal to the change of momentum of mass m_2 after interaction. Since we are dealing with vector quantities and since both sides of the equation above are positive (there is no negative sign), it further states that the two masses undergo a change of momentum in the same direction.

Is this a physical fact?

Please return to page 81. Select an answer that tells the whole story correctly.

CORRECT ANSWER: Impulse is a vector quantity.

To describe an impulse fully, you must give its direction as well as its magnitude. You will recall that force is a vector quantity and, to be strictly correct, the symbol for it should always be written $\vec{F}$. In many situations, though, we omit the vector arrow and write simply F; but if we do this, we must bear in mind that force is a vector quantity.

You will find that a vector quantity multiplied by a scalar quantity always yields a derived quantity that is a vector. There are no exceptions to this rule. In this case we have force (a vector) multiplied by time (a scalar) to yield impulse (a vector). Properly written:

$$\overrightarrow{\text{impulse}} = \vec{F}\Delta t$$

NOTEBOOK ENTRY
Lesson 11

1. Impulse
(a) The impulse of a force is the product of the force (F) and the interval of time (Δt) over which it acts.
(b) A vector quantity multiplied (or divided) by a scalar quantity always yields a vector product (or quotient).

$$\vec{F}\Delta t = \overrightarrow{\text{impulse}}$$

Hence, impulse is a vector quantity, since force is a vector and time is scalar.

Incidentally, few authorities use a symbol for impulse, so we shall follow suit. For our purposes, when we want to symbolize impulse in an equation we shall write $\vec{F}\Delta t$, with or without the vector arrow, depending on the circumstances.

Please go on to page 116.

What impulse is applied to a baseball by a bat that exerts a force of 80 nt on the ball for 0.005 min?

(5)

A 0.40 nt-sec

B 24 nt-sec

YOUR ANSWER --- C

This is too vague a statement, and it doesn't give a definition of a term. It only repeats in words what the terms state in symbols.

The "Δ" does represent "a change of," but it is not placed before the product like this:

$$\Delta m\vec{v}$$

for a very good reason. By inserting the "Δ" between the m and the v factors, we are explicitly saying that the mass does not change while the velocity does. What change could we mean by $m\Delta v$?

Return to page 46 and select another answer, please.

YOUR ANSWER ---- A

This is not correct. You are probably being confused by the symbol for momentum. It is not m; it is p.

If you solve the equation m = pv for p, you get p = m/v, which is a ratio, not a product.

Since momentum is the product of mass and velocity, then m = pv is not correct.

Please return to page 141 and select another answer.

YOUR ANSWER --- C

To obtain this answer, you merely added the initial and final velocities without regard to their directions. In doing this, you forgot the vector nature of velocity and committed a serious error.

Since the body slowed down from 15 m/sec to 0 m/sec just before reversing direction, this segment of its Δv is -15 m/sec. Now, if it reverses direction, the impulse causing this must still be applied in the direction that caused the original deceleration. Therefore, if we call the effect of the first part of the impulse (that which brought the body to rest) a negative quantity, then the new, oppositely directed velocity must have the same "negativeness" because it is being caused by the same negative impulse

Thus, in bringing the body to rest, the impulse caused Δv to be -15 m/sec. Then, in accelerating to 6 m/sec in the opposite direction, there was an additional Δv of -6 m/sec. Now, what is the total Δv?

Please return to page 77 and choose the best answer.

YOUR ANSWER --- B

It may well be that you did not recognize the kind of constancy we had in mind. Think of the previous cart experiment for a moment. The carts had different masses; they interacted as a result of the expansion of the spring; one cart went off to the left with a change of momentum of 0.2 kg-m/sec while the other cart went off to the right with exactly the same change of momentum.

So, in the boy-pushes-man experiment, you might detect this same constancy of momentum if you computed the Δp for the boy and for the man and then compared them. Try it.

Now return to page 151, please. You should have the answer now.

YOUR ANSWER --- A

You didn't try this operation, did you?

This is what happens if we add the members of the pairs:

F		Δt	Result
6	+	0.1	6.1
3	+	0.2	3.2
1	+	0.6	1.6
0.5	+	1.2	1.7

The results are all different. Yet each of the forces acting for the time shown in the same row produced exactly the same effect as the other pairs of force and time. That is, the impulse of each force was the same. Apparently, then, we cannot find the impulse of a force by adding the force to the time interval over which it acts. Such an operation would also involve inconsistency of units, adding newtons to seconds.

Please return to page 33. Then choose another answer.

YOUR ANSWER --- A

You are correct. Acceleration is the rate of change of velocity with respect to time. The "Δ" means rate of change. Thus, Δv is rate of change of velocity, while Δt expresses the time interval or the change of the reading of the clock from t_1 to t_2.

Returning to the Second Law, suppose we substitute $\frac{\Delta v}{\Delta t}$ in place of $\vec{a}$. We then have:

$$\vec{F} = m\vec{a}$$

$$\vec{F} = m\frac{\Delta v}{\Delta t}$$

Now, multiplying both sides by Δt will move this factor to the left side, giving us:

$$\vec{F}\Delta t = m\Delta v$$

But what is $\vec{F}\Delta t$? Of course! It's the symbolic definition of which of the following?

(12)

A Momentum.

B Impulse.

C Acceleration.

YOUR ANSWER --- D

This answer is incorrect in that it ignores the fact that velocities v_2 and v_3 must be taken into account in any calculation of total momentum.

It is perfectly true that if v_2 and v_3 are zero, this is the result that we will get. But we are not looking for the final answer, yet.

Turn to page 30 and find out the correct answer.

YOUR ANSWER --- A

This answer is not justifiable. First, from the Third Law we know that the force acting on m_1 has the same magnitude as the force on m_2. (If Body A exerts a force on Body B, then Body B exerts a force of equal magnitude on Body A in the opposite direction.)

Then, writing the Second Law for m_1 and m_2, we have:

$$F = m_1a_1 \quad \text{and} \quad F = m_2a_2$$

where a_1 and a_2 are the accelerations of m_1 and m_2, respectively. Now, since the force F is the same on both masses, we can equate:

$$m_1a_1 = m_2a_2$$

Then if we solve for a_1, the relationship we want is clearly shown:

$$a_1 = a_2\frac{m_2}{m_1}$$

We said that we were going to double m_2. Thus, m_2 is larger than m_1, and the fraction m_2/m_1 above is larger than unity.

If a_1 equals a_2 multiplied by some number greater than 1, what does that tell you about the comparative size of a_1?

Were you confused as to which mass was increased?

Please return to page 23 and try again.

YOUR ANSWER --- B

You are correct. You used the expression $w = mg$, and since $m = 0.50$ kg and $g = 9.8\ m/sec^2$, then $w = 0.50\ kg \times 9.8\ m/sec^2 = 0.50 \times 9.8$ nt

All right. Let's collect our facts. The equation for determining the time of application of the impulse is:

$$\Delta t = \frac{m\Delta v}{F}$$

We have the following data:

$m = 0.50$ kg $\quad \Delta v = -3.0$ m/sec $\quad F = -(0.50 \times 9.8$ nt$)$

Note the (-) signs before the Δv and the F factors.

We're ready to substitute:

$$\Delta t = \frac{0.50\ kg \times (-3.0\ m/sec)}{-0.50 \times 9.8\ nt}$$

The rest is up to you. Determine the time of application of the impulse. Be certain that you handle the (-) signs properly because time <u>must</u> come out as a positive quantity.

What do you get for Δt?

(18)

A 3.1 sec

B 31 sec

C Neither of these.

CORRECT ANSWER: In the expression $2 \times 20 = 10 \times v_3$, v_3 would have to be <u>4</u>.

Thus, we have:

$$\begin{array}{ccccccc} 2 & \times & 20 & = & 10 & \times & 4 \\ \uparrow & & \uparrow & & \uparrow & & \uparrow \\ m & & v_1 & & M & & v_3 \end{array}$$

So that $40 = 40$.

Now observe what has occurred. The small mass m is 1/5 as large as the large mass M. The equality of the products forces us to assign a value to v_3 which is 1/5 that of v_1 <u>so that equality may be maintained</u>.

In short, then, in an interaction involving the coupling together of the masses after the collision, where the new mass is the sum of the original masses, what must be true of the new velocity after impact compared to the original velocity before impact?

Please return to page 85 and try again!

CORRECT ANSWER: The rifle will have the same momentum toward the south as the bullet has toward the north.

To see how this works out in practice, we'll run through a numerical example involving the firing of a bullet. A rifle having a mass of 2.0 kg fires a 0.0030 kg bullet north at a muzzle velocity of 900 m/sec. What is the recoil velocity of the rifle against the marksman's shoulder?

Symbolizing the quantities:

$$m_b = 0.0030\text{ kg} \qquad m_r = 2.0\text{ kg}$$
$$v_b = 900\text{ m/sec} \qquad v_r = ?$$

The Principle of Conservation of Momentum:

$$m_r \Delta v_r = -m_b \Delta v_b$$

Solving for the change of velocity of the rifle, we have:

$$v_r = \frac{-m_b \Delta v_b}{m_r}$$

Substituting:

$$v_r = -\frac{0.0030\text{ kg} \times 900\text{ m/sec}}{2.0\text{ kg}}$$

$$v_r = \underline{-1.4}\ \underline{\text{m/sec}}$$

Thus, the recoil velocity of the rifle is 1.4 m/sec to the south as indicated by the minus sign. The recoil velocity of the rifle is relatively small compared to the velocity of the bullet. Why?

(28)

A The explosion has more effect on the bullet than on the rifle.

B The mass of the rifle is much greater than the mass of the bullet.

C The marksman's shoulder retards the recoil action.

YOUR ANSWER --- B

That fact that you introduced the (-) sign into the answer is an indication that some of your thinking is following the right lines. But you haven't gone far enough.

Look at it this way: we know that when the moving object is brought to rest from a velocity of 15 m/sec, the change of velocity is -15 m/sec. The minus sign indicates that there has been a decrease of velocity. Now, when it is accelerated in the opposite direction to a new speed of 6 m/sec, the total change of velocity is greater than it was when the body was just brought to rest. Remember that velocity is a vector quantity and that the direction of motion must be considered as well as the speed. An oppositely directed velocity is a "minus" velocity compared to the velocity in the original direction.

Please return to page 77 and select another answer choice.

YOUR ANSWER --- B

Hold on! I'm afraid you've missed the point!

We are using the word momentum to describe the quantity of motion. We have agreed that increasing either the mass or the velocity (or both) of the moving body will increase its momentum.

If, then, we have somehow increased the momentum of the locomotive, we must have increased either its mass, its velocity, or both. If the mass has been increased, then the engine will have more inertia. It will be more difficult for the wood stop to bring it to rest. Therefore, it seems reasonable that the probe will have to penetrate more deeply into the wood before enough retarding force can be brought to bear on the locomotive to stop its motion.

On the other hand, if the momentum has been increased by raising the rolling speed, then a given force will need more time to decelerate the locomotive to rest. Again, this implies that the probe will have to penetrate more deeply in order to do the job of stopping the engine.

Please return to page 7 and read the question again. You should be able to select the right answer now.

CORRECT ANSWER: At the highest point in its flight, the momentum of the ball is zero.

The ball must stop moving at the highest point, preparatory to reversing its direction for the return downward. Thus, if it stops moving, its velocity is zero, and the product mv is also zero.

A third question about the ball: What impulse stops the motion of the ball?

(16)

A -1.5 kg-m/sec

B 1.5 kg-m/sec

C -1.5 nt-sec

D 1.5 nt-sec

YOUR ANSWER --- B

You know that the momentum of the system after the collision must be equal to the momentum before the collision. Before the collision, only the empty freight car is in motion (relatively small mass), while after the collision both the empty and loaded freight cars (relatively large mass) are moving together. Since momentum is a product of mass and velocity, if the large mass after the collision is to have the same momentum as the smaller mass before the collision, what must be true of the new velocity?

Please return to page 85. Then choose a more suitable answer.

This page has been inserted to maintain continuity of text. It is not intended to convey lesson information.

YOUR ANSWER --- C

This answer is numerically correct, but we'd like to talk about the algebraic sign for a moment.

We found the momentum before the force acts to be:

$$p = 10 \text{ kg} \times 10 \text{ m/sec} = 100 \text{ kg-m/sec}$$

Although we said nothing about it explicitly, we are tacitly taking this to be a positive momentum, to be later compared with the momentum after the force acts. Suppose the object had been moving eastward initially; then we are arbitrarily calling an eastward direction positive, thereby assigning a (+) sign to the eastward momentum.

You already know, however, that after the force acts, the body will be moving westward. To be consistent, we must therefore refer to westward motion as negative compared to the positive eastward motion.

Please return to page 26. You should be able to select the right answer now.

YOUR ANSWER --- A

You are correct. The impulse of a force is a derived quantity (derived or obtained from F and Δt), so its units must be derived in the same way. Since impulse is a product, that is, F x Δt, then its unit is a product: nt x sec or nt-sec.

Our next concern lies with this question: Is impulse a scalar or vector quantity? Well, let's go back to our demonstration door and see how further thought about it will help.

Suppose we have a door that will close firmly and surely if a force of 2 nt is applied to it for 2 sec in the right direction. The impulse in this case would be 2 nt x 2 sec = 4 nt-sec. We then ask this straightforward question: Since an impulse of 4 nt-sec will close this door, will an impulse of 5 nt-sec just as surely close it? Your tendency is to answer in the affirmative, but this is a hasty answer because an impulse of 5 nt-sec applied to the door in the wrong direction will cause it to open wider rather than to close.

You can think of similar examples involving other things besides doors. To the left of a golfer is the last hole; to his right is a water hazard. An impulse of 1.6 nt-sec is enough to move the ball into either of these. All right. Suppose the golfer gives the ball an impulse of 1.6 nt-sec. Into which--the hole or the water hazard--will the golf ball go?

(4)

A Into the hole.

B Into the water hazard.

C The data are insufficient to answer the question.

YOUR ANSWER --- B

The Principle of Conservation of Momentum as stated in notebook entry 4(b) is a <u>universal principle</u>. It applies not only to perfectly elastic collisions but also to inelastic and partially elastic collisions, too.

You were probably confused by the introduction of the word "inelastic." <u>The type of collision does not affect the validity of the conservation principle.</u>

Please return to page 103 and select the right answer.

YOUR ANSWER --- B

Your arithmetic contains an error. Be careful of that decimal point!

Repeat the calculations, making sure that your substitutions are correct; then please return to page 56 and choose the right answer.

YOUR ANSWER --- A

This answer is a bit vague and therefore incorrect. Remember, science is an exact discipline.

Momentum has only one form; there can be no "slightly different" one:

$$\vec{p} = m\vec{v}$$

This is the only defining equation for momentum, and is considered as absolute. The moment you insert a new term like "Δ," you change the equation so that it no longer represents the same thing that it did previously.

If you read out "$m\Delta\vec{v}$" orally, you might say it is mass times a change of velocity. Since for a given body the mass is constant, we don't want to place the "Δ" in front of the product like this:

$$\Delta m\vec{v}$$

If we did, you might think that the mass was changing or that both the mass and velocity were being altered.

You can reason this out. There is another choice which defines the term accurately.

Please return to page 46 and try again.

YOUR ANSWER --- B

Have you forgotten what you started out to find? Your listing of data for this problem should tell you what you are required to determine. We must conclude that you didn't copy it as you were requested.

Please return to page 88 to review and copy the listing.

This page has been inserted to maintain continuity of text. It is not intended to convey lesson information.

YOUR ANSWER --- B

In the left diagram of Figure 5 on page 50, the symbol v_2 evidently applies to m_2 just before impact occurs. Since v_2 is given as zero at impact, then can m_2 be moving in any direction? If it were moving at all, it would have a definite velocity one way or the other.

Please return to page 50 and select the right answer.

CORRECT ANSWER: If the depth is the same, then the momentum of the probe in this situation must be exactly the same as it was when it was mounted on the locomotive.

Remember, we are measuring momentum or quantity of motion by the depth of penetration of the probe. If the depth of the fired probe is the same as the depth of the probe carried by the engine, then the momentum must be the same in each case.

To keep the conditions straight, we are using rather unusual symbolism. For the locomotive probe, M is mass and v is velocity to help you keep in mind that the mass is very large. For the fired probe, the mass m is small, but the velocity is large, so we have taken the liberty of symbolizing it with V. Clearly, in this example, a given amount of momentum can be attained by using either a large mass and a small velocity or a small mass and a large velocity.

From these considerations alone, we have a clue as to the definition of momentum. The only way the M and v can be put together to give the same result as m and V, is by means of a product. If we write $Mv = mV$, and, if the masses and velocities are chosen correctly, it is possible to establish an equality.

So, the momentum of a body moving with uniform velocity is defined as the product of mass of the body and its velocity. If momentum is symbolized by p, then the defining equation is which of the following?

(8)

A $m = pv$

B $p = mv$

C $v = mp$

YOUR ANSWER --- D

This is incorrect.

After impact, v_3 is zero, making m_1v_3 drop out. But m_2v_2 cannot be zero if m_2, the mass of the block, and v_2, the initial velocity of the block, are perfectly good finite quantities.

Please return to page 54; then read the answers over carefully in connection with the text above before selecting another answer.

YOUR ANSWER --- A

You are correct. A change of velocity from 10 m/sec to 2.0 m/sec in the opposite direction is a Δv of -12 m/sec. Thus:

$$\text{impulse} = F\Delta t = m\Delta v$$
$$= 10 \text{ kg} \times (-12 \text{ m/sec})$$
$$= -120 \text{ kg-m/sec} = \underline{-120} \ \underline{\text{nt-sec}}$$

Here is the second question. What is the magnitude and direction of the force?

We can determine the magnitude of the force by solving the following equation for F:

$$F\Delta t = m\Delta v$$

Hence:

$$F = \frac{m\Delta v}{\Delta t}$$

$$F = \frac{-120 \text{ kg-m/sec}}{4.0 \text{ sec}}$$

$$F = -30 \text{ kg-m/sec}^2 = \underline{-30} \ \underline{\text{nt}}$$

We find, then, that the force acting on the body to cause it to change velocity as described has a mangitude of 30 nt. What does the (-) sign in the answer signify?

(22)

A The force is a negative one.

B The force acts in the same direction as the body was initially moving.

C The direction of the force is opposite that of the initial motion.

YOUR ANSWER --- C

You are correct. The right answer is 0.31 sec. Both of the answers given were incorrect because of misplacement of decimal points.

NOTEBOOK ENTRY
Lesson 11

(Item 3)

(d) Calculations which relate impulse to momentum must take into account the vector nature of these quantities. A simple convention used for this purpose is:

(1) When a numerical value is substituted for a retarding force (F), the number should be preceded by a (-) sign. If the force F produces increasing velocity, the number is a positive quantity.

(2) When a numerical value is substituted for a decreasing velocity (Δv), the number should be preceded by a (-) sign. If Δv is an increase in velocity, then the number is positive.

This notebook entry is not quite complete. Another idea must be incorporated into your thinking on this subject. We shall point out what we mean by a few examples.

Suppose an object is moving toward the right with a velocity of 15 m/sec. An impulse then acts upon it, also toward the right, resulting in an increase of speed. The change of velocity, or Δv, is obviously the new speed minus the initial speed. Say the new speed after the impulse has vanished is 22 m/sec; then Δv must be 7 m/sec. We would make this a positive quantity (i.e., $\Delta v = +7$ m/sec) according to the rule above. So far so good. Considering the same object with a uniform velocity of 15 m/sec to the right, what is the value of Δv if the impulse acts toward the left, causing the new speed to be 8 m/sec?

(19)

A -7 m/sec

B 7 m/sec

YOUR ANSWER --- C

You know that the momentum of the system after the collision must be equal to the momentum before the collision. Before impact, only the empty freight car (a relatively small mass) is in motion; after the collision, however, the mass is substantially increased by the coupling that occurs between the empty and loaded carts. Since momentum is a product of mass and velocity, if the large mass after the collision is to have the same momentum as the smaller mass before the collision, can the two velocities possibly be the same?

Please return to page 85 and choose a better response.

YOUR ANSWER --- C

You are correct. If we keep the correct units for all our quantities well in mind at all times, we need not emphasize them so strongly in the rest of this lesson.

Impulse and momentum, although related, tell us different things. Impulse and momentum has a cause-and-effect relationship in many real situations. Impulse can be the cause of an increase in momentum, or a decrease in momentum, but a change in momentum is seldom thought of as being the cause of an impulse. Impulse is a property of a force; the force can produce an impulse only if it is allowed to act for a finite time. It is the effectiveness of a force in producing motion. Consequently, we may think of impulse as the cause of a change of motion and the change of momentum as the effect of an impulse.

Momentum, however, as the "quantity of motion" possessed by a moving mass, provides some indication of the damage this mass can do when it collides with another body. Given a plaster wall as a target, a steel ball moving with reasonable speed can cause quite a dent, but a ping-pong ball moving at the same speed will have no such effect. But, if the ping-pong ball can be made to move fast enough, it will either dent the plaster wall or destroy itself. Even a straw blown by a high-speed wind has been known to penetrate the trunk of a tree. Thus, momentum is a property of a mass; the mass has momentum because it is moving. The quantity of motion it has is a function of both mass and velocity.

Please go on to page 147.

As the basis for our next problem, we shall concern ourselves with the answers to certain questions relating to a 0.50-kg ball that is thrown straight upward with an initial velocity of 3.0 m/sec. (Copy these figures for use in answering the questions that follow.)

What is the initial momentum of the ball?

(15)

A 1.5 kg-m/sec, upward.

B 1.5 nt-sec, upward.

C 15 kg-m/sec, upward.

YOUR ANSWER --- C

You are correct. You were careful of both the magnitude and direction of the vector quantities in selecting this answer. A change of momentum may be either an increasing or a decreasing momentum. We use (+) and (-) signs to distinguish between them, and (+) sign indicating an increasing momentum and the (-) sign showing that the momentum is decreasing. In this problem, the momentum decreases as the ball rises; thus $\Delta p = -1.5$ kg-m/sec. Since impulse = Δp, then the impulse that stops the ball is -1.5 nt-sec.

A fourth question: How long did this impulse act?

Before trying to solve this problem, we might do well to review an important idea relating to force vectors. In the lesson on Newton's Laws of Motion, we had occasion to solve problems in which a retarding force played a part. You should remember that we identified the retarding action by placing a (-) sign before the force symbol. Now in the case of the rising ball, gravity acts as a retarding force, so in:

$$F\Delta t = m\Delta v$$

the numerical value used for F must be preceded by a (-) sign.

Since we want to find the time interval during which the impulse acts, we must solve this equation first for Δt. Do this; then check your literal solution by turning to page 67.

YOUR ANSWER --- D

This is too hasty a conclusion!

None of the answers may <u>look</u> right to you on first inspection, but one of them is!

We hope you didn't lose your copy of the data, but here it is again, just in case:

m_1 = mass of empty freight car (6.0×10^4 kg)
v_1 = velocity of empty freight car before impact (3 m/sec)
m_2 = mass of loaded freight car (1.2×10^5 kg)
v_2 = velocity of loaded freight car before impact (0 m/sec)
v_3 = velocity of empty freight car after impact (?)
v_4 = velocity of loaded freight car after impact (?)

Work the problem out carefully, please. Then return to page 51 and choose the right answer.

YOUR ANSWER --- A

This answer is not reasonable.

If doubling either m or v alone causes the quantity of motion to double, then the quantity of motion must be directly proportional to <u>both</u> these quantities:

$$\text{quantity of motion} = kmv$$

It helps considerably to write the relation as a proportionality. From this, you should be able to see immediately that the kind of cancellation you are talking about could not possibly occur.

Please return to page 83 and select another answer.

CORRECT ANSWER: The change of momentum of m_2 is 0.20 kg-m/sec toward the right.

That is, $\Delta p_2 = m_2 \Delta v_2 = 1.0$ kg x 0.20 m/sec = 0.20 kg-m/sec toward the right.

It appears from this example that experimental evidence points to a kind of constancy of momentum in situations where bodies interact without the application of external forces.

Let's take another example. A boy and a man are standing on "frictionless" ice. The boy reaches out and pushes the man away from him; they both start to move away from each other. Now, if the boy has a mass of 50 kg and the man a mass of 80 kg, the man moves off at a speed of 0.25 m/sec while the boy moves in the opposite direction at a speed of 0.40 m/sec. Assuming that this experiment was actually performed, would you say that it points to the kind of constancy mentioned above?

(26)

A Yes.

B No.

C I don't know.

YOUR ANSWER --- B

When the cars couple together, in effect they then form a single moving body. For consistency, we have assigned v_3 as the velocity of the empty freight car after impact and v_4 as the velocity of the loaded freight car after impact. But if the two cars form a single body, can v_3 possibly exceed v_4 in magnitude? The empty car would have to go through the loaded one for this to be true.

Please return to page 88. The answer should now be obvious.

YOUR ANSWER --- C

You are correct. Mass is a scalar quantity; velocity, a vector.

Consequently, to be rigorous we ought to write:

$$\vec{p} = m\vec{v}$$

Note that the vector arrow on the right side is drawn above the v and not above the m. It is velocity that is the vector in this expression.

Ready for units for momentum? We think that you now have enough experience to work out the unit for yourself. Going back for a moment to impulse, you will remember that we obtained the units this way:

$$\text{impulse} = \vec{F}\Delta t$$

$$\text{impulse} = \text{nt} \times \text{sec} = \underline{\text{nt-sec}}$$

Let's see you do the same trick for the units involved in momentum. Which of the following is the unit used to measure the described momentum? (In the MKS system, of course.)

(10)

A $\frac{\text{kg-cm}}{\text{sec}}$

B $\frac{\text{kg-m}}{\text{sec}}$

C $\frac{\text{kg-m}}{\text{sec}^2}$

D $\frac{\text{nt-m}}{\text{sec}}$

YOUR ANSWER --- B

We agree with this answer. The (-) sign is essential to tell you that the body has a final momentum in a direction opposite that of its initial momentum.

We shall direct our attention next to momentum considerations involved in the interaction of two bodies. As an example, we link two laboratory carts together as shown in Figure 3 by means of a cord and a compressed spring. To make sure that we don't bring external forces into play, we burn the cord, allowing the spring to force the carts apart in a kind of "explosion." The spring drops to the table as the carts move away from each other. Since these are real carts in a real laboratory situation, they soon come to rest as a result of friction.

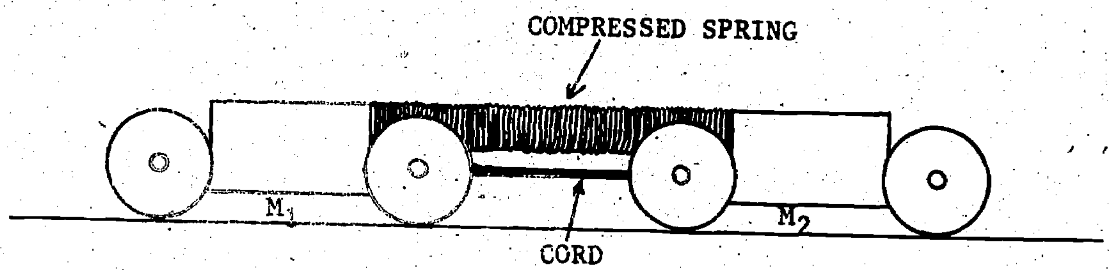

Figure 3

Let us assume that we have very carefully equalized the masses m_1 and m_2. We shall also assume that we have a good laboratory method of determining the velocities of the two carts at the instant the spring drops away from the system after the cord is burned.

Basing your decision on previously learned physical principles, what do you think the velocity measurements would show in this case?

(24)

A The speed of m_1 (call this v_1) would be equal to the speed of m_2 (call this v_2).

B The velocity of m_1 would be exactly the same as the velocity of m_2.

C The speeds for the two masses would be different.

YOUR ANSWER --- A

To be sure, the explosion of the powder has more effect on the bullet than on the rifle in the sense that the bullet visibly travels at a much higher speed just after the explosion. But this is merely repeating the question. We want to know why the explosion causes the bullet to travel quickly toward the north, while the rifle moves comparatively slowly toward the south.

So kindly return to page 127 and think out the question more carefully before selecting another answer.

WORKSHEET

Please listen to Tape Segment 1 for this lesson before starting to answer the questions below. Answer selections must be made on the AV Computer Card.

QUESTIONS

1. Would the first basemen playing baseball on the Moon need a mitt?

   A No, because the impact of the ball depends on the weight of the ball and the ball weighs less on the Moon than on Earth.
   B No, because the flat trajectory would make a mitt unnecessary.
   C Yes, because the gravitational force on the Moon is less so that the ball would rise to a greater height before coming down.
   D Yes, because momentum depends on mass and velocity; the mass of the ball on the Moon is the same as it is on the Earth.

2. If the same baseball were dropped from the top of an Empire State building on the Moon, straight down, would the person who tried to catch it require a mitt?

   A No. The weight of the ball is 1/6 its weight on Earth.
   B No. The magnitude of gravitational acceleration on the Moon is so small that the ball would not acquire much velocity even in a fall like this.
   C Yes. The momentum of the ball on reaching the ground would be smaller than it would be in an equal Earth-fall, but would still be large enough to make a mitt necessary.
   D Yes. The momentum of the ball would be exactly the same as it would have been for an equal Earth-fall.
   E No. The definition of momentum as applied to conditions on the Earth does not apply to conditions on the Moon.

Please return now to page 4 of the STUDY GUIDE.

WORKSHEET

Please listen to Tape Segment 2 for this lesson before starting to answer the questions below. Answer selections must be made on the AV Computer Card.

Data Item A: Mass of the hammer = 4.0 kg
Speed of the hammer on impact = 5.0 m/sec
Contact time, hammer on nail = 0.0020 sec

QUESTIONS

3. What was the value of the average force applied to the spike by the hammer?

   A Between 2000 and 3000 lb
   B Between 3000 and 4000 lb
   C Between 1000 and 2000 lb
   D Between 500 and 1000 lb
   E Just below 500 lb

4. In the example above, by how much would the average force have changed if the mass of the hammer had been 6.0 kg instead of 4.0 kg, assuming other quantities constant?

   A Twice as great
   B 1-1/2 times as great
   C Three times as great
   D Six times as great
   E None of these

5. In the example as originally stated, suppose the hammer had had a contact time of 0.0010 sec with the head of the spike. By how much would the average force have changed from its original value?

   A 10 times as great
   B 1/10 as great
   C It would not have changed at all
   D 2 times as great
   E 1/2 as great

Please return now to page 94 of the STUDY GUIDE.

WORKSHEET

Please listen to Tape Segment 3 for this lesson before starting to answer the questions below. Answer selections must be made on the AV Computer Card.

Data Item A: Mass of ball = m = 100 g or 0.100 kg

Velocity of ball on impact = v_o = 30 m/sec

Bounce-back velocity of ball = v = -30 m/sec

Applicable equation: $F\Delta t = m\Delta v$

Substitution: $F\Delta t = 0.100 \text{ kg} \times (-60 \text{ m/sec})$

Solution: $F\Delta t = -6.00$ nt-sec. This is the impulse of the wall on the ball.

QUESTIONS

6. The impulse of the ball on the wall is

   A -6.0 nt-sec
   B +6.0 nt-sec
   C -12.0 nt-sec
   D +12.0 nt-sec
   E +600 nt-sec

7. The problem above is based on an idealized condition in which the wall is considered unyielding. If the wall actually yielded to the impact to some extent, then

   A the bounce-back velocity of the ball would have been greater than -30 m/sec.
   B the bounce-back velocity of the ball would have still been - 30 m/sec.
   C the bounce-back velocity of the ball would have been smaller than -30 m/sec.
   D the ball would have had a larger rebound momentum than 6.00 kg-m/sec.
   E the ball would have had a rebound momentum between 6.00 and 8.00 kg-m/sec.

Please return now to page 39 of the STUDY GUIDE.

WORKSHEET

Please listen to Tape Segment 4 for this lesson before starting to answer the questions below. Answer selections must be made on the AV Computer Card.

For this tape segment you will need a single-concept projector and the brief film entitled CONSERVATION OF MOMENTUM - ELASTIC COLLISIONS.

8. In the film, when a 1M glider in motion collided with another 1M glider at rest,

A the momentum of the initially moving glider became half its original size.
B the momentum of the initially resting glider acquired a momentum equal to half the momentum possessed by the initially moving glider.
C the total momentum of the system was reduced to half of its initial value.
D the total momentum of the system was increased to twice its initial value.
E the momentum of the initially resting glider became equal to the momentum possessed originally by the initially moving glider.

9. The driving glider (glider initially in motion) in one of the experiments was a 1M. This collided with a 3M glider at rest. After impact, the magnitude of the momentum of the

A 3M glider was equal to the magnitude of the momentum of the 1M glider.
B 3M glider was greater than the magnitude of the momentum of the 1M glider.
C 1M glider was greater than the magnitude of the momentum of the 3M glider.
D 1M glider became zero because it stopped moving.
E 3M glider was zero because its velocity was zero.

10. A second collision of the 1M and 3M gliders occurred after the conditions specified in (9) above were completed. After this second collision, the 3M glider had a velocity of

A Zero
B Slightly positive
C Slightly negative
D Same as before impact
E none of these

Please return to page 103 of the STUDY GUIDE.

WORKSHEET

Please listen to Tape Segment 5 for this lesson before starting to answer the questions below. Answer selections must be made on the AV Computer Card.

For this tape segment you will need a single-concept projector and the brief film entitled CONSERVATION OF MOMENTUM - INELASTIC COLLISIONS.

Data Item A:

Exp. No.	Mass of Glider A	Mass of Glider B	Coupled Mass	Time Glider A	Time Coupled Mass
1	1M	1M	2M	2.25 sec	4.62 sec
	1M	1M	2M	2.39 sec	4.82 sec
2	1M	2M	3M	2.11 sec	6.42 sec
	1M	2M	3M	2.05 sec	6.26 sec
3	2M	1M	3M	2.16 sec	3.30 sec

GLIDER A, initially in motion, is the driving glider

GLIDER B, initially at rest, is the target glider

Data Item B: As explained in the third paragraph of page 60 of the STUDY GUIDE, the velocity of the coupled mass after collision is obtained from the ratio:

EQ.1 — $\dfrac{\text{mass initially in motion}}{\text{coupled mass}} = \dfrac{\text{coupled velocity}}{\text{initial velocity}}$

In the experiment, the time over equal distances is measured. Since the time required to cover a given distance with uniform velocity is inversely proportional to the velocity,

EQ.2 — $\dfrac{\text{coupled velocity}}{\text{initial velocity}} = \dfrac{\text{Glider A time}}{\text{coupled time}}$

Combining equations 1 and 2:

EQ.3 — $\dfrac{\text{mass of Glider A}}{\text{coupled mass}} = \dfrac{\text{Glider A time}}{\text{coupled time}}$

Now let us use the figures obtained in the first trial of Experiment 1 above. The mass of Glider A divided by the coupled mass is 1 divided by 2, or 1/2. Conservation considerations tell us that Glider A time divided by the

(next page, please)

computed time should also turn out to be 1/2 or 0.500. Substituting the measured times shown in the Table in the right member of EQ.3 gives us

$$\frac{2.25}{4.62} = 0.488. \quad \text{This is a \% error of } \frac{0.012}{0.500} = 2.4\%$$

Study the methods used in the above calculation. Then repeat the same calculation using the figures for the remaining 4 trials. In each case compute the % error of the measured ratio as compared with the ratio predicted for the different masses . Select the % error for each of the trials from these choices:

- A between 1.6% and 1.8%
- B between 1.8% and 2.3%
- C between 0.6% and 0.9%
- D between 1.0% and 1.6%
- E greater than 2.3%

11. Experiment 1, Trial 2. Punch card in one of the letters given above.

12. Experiment 2, Trial 1. Similarly punch card.

13. Experiment 2, Trial 2. Similarly punch card.

14. Experiment 3. Similarly punch card.

PLEASE RETURN TO PAGE 79 OF THE STUDY GUIDE.

HOMEWORK PROBLEMS

Lesson 11

1. An unbalanced force applied to a car of mass 1500 kg causes the speed of the car to increase uniformly from 10 m/sec to 25 m/sec over an interval of 3 sec. Calculate

   (a) the initial momentum of the car;
   (b) the final momentum of the car;
   (c) the magnitude of the force that caused the increase in speed.

2. A 1000-kg block is pushed by a constant force for 56 sec, and as a result, its speed changes from 4 m/sec to 32 m/sec.

   (a) What was the change of momentum of the block?
   (b) What was the magnitude of the constant force?

3. Two toy cars of mass 6 kg and 2 kg are held together with a string. There is a compressed spring between them. When the string is burned, the 6 kg car moves off with a speed of 0.1 m/sec. What was the speed of the other car?

4. A 2-kg glider on an air track moving at a speed of 9 m/sec collides head-on with a second glider of mass 1.5 kg. Both gliders come to a stop upon impact.

   (a) What kind of collision is this?
   (b) What must have been the total momentum of the system before the collision?
   (c) What was the momentum of the second glider before the collision?

5. A 1-kg glider on an air track collides with a second glider on the same track. If the 1-kg glider was moving at 5 m/sec and the second glider was at rest, what was the mass of the second glider for the following post-collision conditions: the 1-kg glider reverses direction and moves at 1 m/sec; the second glider moves forward at 2 m/sec.

6. A rifle of mass 2.0 kg fires a 10-g bullet horizontally. If the muzzle velocity of the bullet is 500 m/sec, what is the recoil velocity of the gun, assuming zero friction.

7. A 600-kg car traveling at 20 m/sec collides with a stationary truck of mass 1400 kg. The two vehicles lock together after the collision. What is the velocity of the combined mass after the collision?